SELLING GEOPHYSICS: SOME OBSERVATIONS ON CREATING AND MARKETING A GEOPHYSICS PROGRAM IN STATE GOVERNMENT

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ABSTRACT

Geophysical methods offer significant advantages to "traditional" drilling and sampling techniques, including correlation between boreholes, increased data quality and reduced cost. However, from a management standpoint, the decision to employ geophysical techniques may not be based on increased data quality. Cost can be the deciding factor when competing for limited resources (i.e., dollars). The California Department of Transportation (Caltrans) investigated the cost-effectiveness of geophysical techniques for design and rehabilitation of California's transportation infrastructure, and for determining whether in-house programs or consultant contracts were the most appropriate means of providing those services.

Cost comparisons, were made between drilling and geophysics, between in-house and consultant geophysics costs, and the costs of not having the necessary geotechnical data. The largest potential cost reduction within Caltrans is in seismic design of structures. Geophysical testing plays a significant role in the development of seismic ground response models. In the absence of an accurate ground response model, structure costs can increase by a minimum of 20%, a factor that can equal millions of dollars for large structures.

By correlating with direct observations, the use of geophysics in conjunction with drilling can reduce foundation characterization costs by reducing the number of lab analyses and boreholes required. For a typical foundation investigation in California, if just one borehole is eliminated via geophysics, the total cost to Caltrans for geotechnical data acquisition can be reduced by 25%.

The initial savings to Caltrans by performing borehole geophysical services in-house amounted to 70% of the contract costs for the same services. From that savings alone we were able to fully amortize initial equipment expenses in less than two years. Savings for surface geophysical services were lower, but at 54% of typical contract costs, the competitive cost comparison enabled creation and expansion of an in-house geophysical services program within Caltrans.

Several factors that contributed to successful implementation of our geophysical program were 1) management commitment to capitalization, 2) documentation of benefits and workload, 3) ease of access to services (availability), 4) establishment of good working relationships between offices, and 5) a favorable political climate. As new services have been added to meet the changing needs of our clients, we've also experienced an increase and diversification of our client base, with an increase in demand of over 450% in two years.

INTRODUCTION

Judicious application of geophysical techniques to geotechnical investigations can result in significant cost savings. These savings apply to the cost of the investigation, by supplanting more expensive investigative methods, and to the cost of the structure by supplying critical geotechnical data.

Potential benefits of geophysics for geotechnical and environmental investigations have been widely distributed (Benson *et al*., 1982, Ward, S.H., 1990, U.S. Army Corps of Engineers, 1997). Surface geophysical methods offer some significant advantages to the "traditional" investigative technique of drilling and sampling. Surface geophysical methods can investigate larger volumes in shorter time, are more mobile and are "environmentally friendly". In areas of limited access or environmental restrictions, surface geophysics may be the only means of acquiring geologic data. Borehole geophysics also has advantages over rock and soil sampling. Sample density with borehole geophysics is usually much greater, measurements are made under in-situ conditions, more representative volumes of material are measured and problems with sample degradation and storage are eliminated. Some standard lab and field data, such as density and standard penetration test (SPT) N values ("blow counts"), can be calculated from geophysical measurements. For most non-destructive testing of foundation materials, including low-strain moduli and cross-hole tomography, borehole geophysics is the only means of data acquisition.

Despite those advantages, geophysics will never entirely replace drilling, nor should it. Geophysical testing provides an indirect measurement of geologic conditions that should always be substantiated with direct observation. However, use of geophysics in conjunction with drilling can reduce costs by reducing the number of lab analyses and boreholes required, through increased accuracy of in-situ analyses, by filling data gaps between holes, extrapolating into unknown areas, and by focusing drilling activities through initial geophysical reconnaissance.

For a knowledgeable project engineer or geologist at the project level, the decision to augment a drilling program with geophysics is usually made based on perceived benefit toward solving the problem at hand. However, when considering competition for limited resources, from a management perspective, the decision to employ geophysics may not be based on increased data quality. In that instance, cost can be (and usually is) the deciding factor.

At the California Department of Transportation (Caltrans), I investigated the cost-effectiveness of specific geophysical techniques for design and rehabilitation of California's infrastructure. I attempted to enumerate savings accrued through increased efficiency of geotechnical investigations. In addition, cost comparisons between in-house work and consultant services were also made to evaluate the most appropriate means of providing those services. The result of this evaluation, combined with a favorable political climate, led to the creation and expansion of a geophysics program within Caltrans. In this paper, I present a brief chronological history of events that led up to the formalization of the geophysics group. I also summarize the results of the cost-effectiveness evaluation. Finally, I present some observations and advice to those in other state agencies interested in pursuing a similar course.

BACKGROUND

Geophysics in Caltrans was not a novel idea. Seismic refraction and electrical resistivity methods were applied to geotechnical problems at least as far back as the early 1960's. Research into use of seismic velocity data for determining rippability and estimating earthwork factors was completed in the 1970's. In the 1980's and early 1990's, attempts were made at shear-wave refraction studies, and interval-velocity logging was introduced. However, the scope and quantity of this work was limited throughout. Only a few geologists and technicians performed this work on an *ad hoc* basis, with their primary function being engineering geology, not geophysics. A core group of people with geophysics education and experience were not dedicated to that task. As a result, geophysical knowledge and expertise within Caltrans lagged.

Change, albeit initially slow, began around 1990. The significant event marking this change was the Loma Prieta Earthquake in October of 1989. The extensive damage in the San Francisco Bay area highlighted, with tragic consequences, the vulnerability of California's transportation infrastructure to moderate and large seismic events. This weakness was reinforced just over 4 years later and 400 miles further south, when America's costliest earthquake (to-date) struck near Northridge.

Besides causing structural damage and loss of life, the Loma Prieta earthquake resulted in substantial economic losses through disruption of the state's transportation system. These economic losses were felt statewide, and pinpointed the need for systematic hardening of road, highway and rail structures to minimize damage and disruption of the transportation network due to seismic events. To this end, Caltrans launched the Seismic Retrofit Program, an ambitious initiative designed to inspect and evaluate every structure in the State Highway System for seismic risk and, if necessary, repair and retrofit those structures to minimize that risk. For those structures identified at risk of earthquake damage, the program required the combined efforts of engineers, geologists and geophysicists to collect geophysical data, derive the appropriate seismic response models for the foundation materials, and evaluate the engineering designs for anticipated seismic loads.

The Seismic Retrofit Program demonstrated a clear need for personnel trained and experienced in a variety of geophysical methods, and it marked the first time at Caltrans where geophysical methods were systematically applied on a large scale. In the program, the primary task of the geophysicist was to acquire seismic velocity data critical for developing ground response models. Both compressional and shear velocity data were used in the modeling process. The data were collected through borehole geophysical logs, a process where probes are passed down a borehole and measurements are made at discrete intervals. Initial logs consisted of a locking geophone and a shear wave source at the surface. These interval velocity logs proved time consuming and were limited in depth. In 1992, logging efficiency significantly improved with the acquisition of a downhole shear-wave logging system.

In addition to velocity logging, electrical resistivity and natural gamma logs were also recorded at larger structures, to assist in geologic interpretation and for the development of geologic cross-sections. For most of the duration of the Seismic Retrofit Program, shear-wave logging was performed in-house, but electrical resistivity logging was out-sourced under contract. This created logistical difficulties because two separate crews had to mobilize at the same job site, with one crew on standby while the other logged. When the structure in question was over water, as with our major toll bridges, additional expense was incurred in having to place an entire barge on standby for the duration of logging operations. In the latter half of 1995, with our geophysical logging contract due for renewal at the end of the fiscal year and continued funding for the retrofit program in question, we considered numerous cost-saving measures, one of which was assumption of the electrical resistivity logging function. From that analysis, we saw that performing this function in-house would realize significant savings and quickly recoup the initial equipment investment. In June of 1996 the logging contract was allowed to expire and Caltrans assumed in-house responsibility for geophysical logging functions. This decision marked the beginning of a formal geophysical service function within Caltrans.

COST EFFECTIVENESS OF GEOPHYSICS

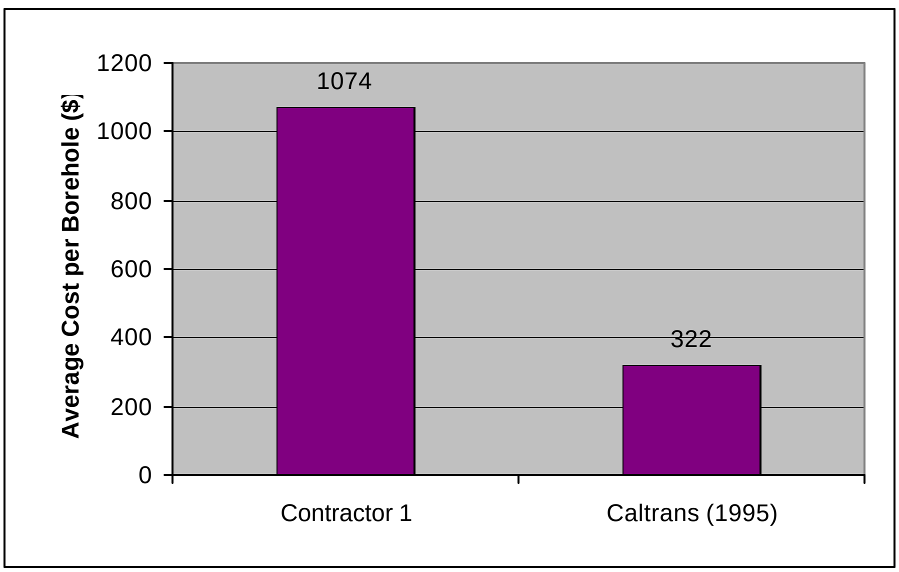

Figure 1. Initial comparison of 1995 contract vs. in-house costs for borehole geophysical services.

At this point, discussion of cost comparisons is warranted. An appropriate comparison separately assesses the two fundamental types of geophysical surveys: surface and borehole, and compares both total savings to the project and in-house versus contract costs. I feel it important to point out that this comparison is not intended as a blanket criticism of the consulting industry. Indeed, we still utilize consultant services for some of our geophysical surveys, where peak workload requires augmentation of our resources or where we do not possess particular equipment or expertise (nobody knows everything). Instead, the comparison is intended to identify specific areas where we, as a government agency, should focus the expenditure of finite taxpayer dollars in a manner concordant with our fiduciary responsibility to avoid profligacy.

Borehole Geophysics Cost Comparisons

Starting with borehole geophysics, evaluation of cost-effectiveness was done two ways: by a comparison of in-house versus consultant costs for data acquisition and by potential savings on investigation or structure costs. For in-house versus consultant costs, report preparation and presentation are not compared; sufficient Caltrans contract data are not available.

The cost-effectiveness of in-house services was established in 1996, when (what was then known as) the Geological Services Unit incorporated borehole geophysical logging services previously performed under contract. Because mobilization costs could be significantly reduced by combining electrical resistivity logging with our existing shear-wave logging services, the savings to Caltrans amounted to 70% of the contract costs for the same services (Figure 1). From that savings alone we were able to fully amortize the initial equipment expenses in less than two years.

As additional geophysical logging tools were added to the program, the earlier cost comparison was no longer adequate. Another comparison, this one incorporating mobilization costs, was made between in-house costs and current and past contract expenses (incorporating the previous contract figures and another, project-specific contract). Even factoring in Caltrans' mobilization expenses, performing geophysical logging in-house results in savings of 38 percent below contract rates (Figure 2).

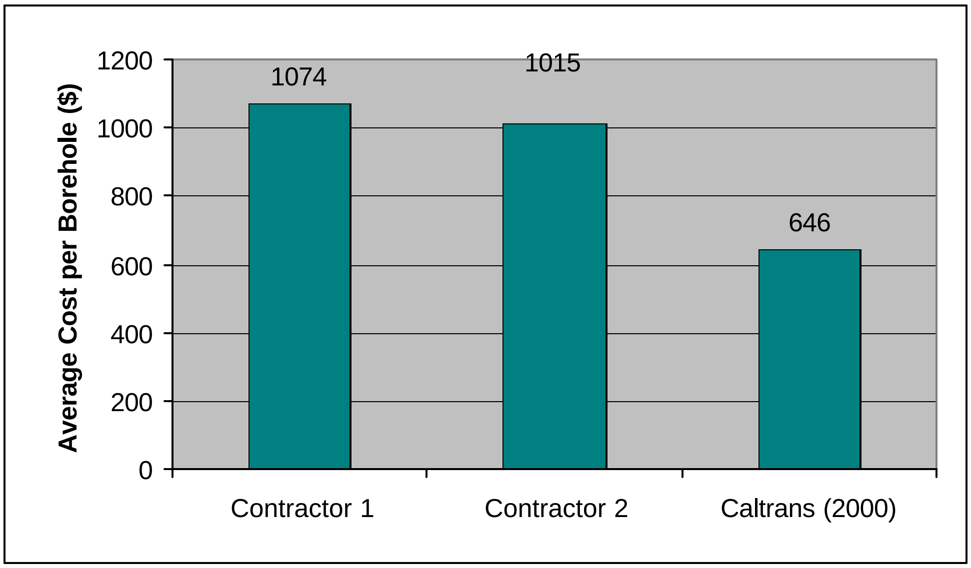

Figure 2. Comparison of year 2000 in-house vs. consultant field acquisition costs for expanded geophysical logging services

Some in-situ geotechnical data used for roadway and foundation design can only be acquired with geophysical methods. Velocity logging is a prime example. In-situ measurements of formation velocity are used for critical structures to derive seismic ground response models for structure design. Where accurate estimates of seismic ground response are not obtained, two adverse scenarios can occur. In the first, lack of accurate seismic ground response models result in over-designed structures. From estimates provided by the OSF-Geotechnical Earthquake Engineering Branch (pers. commun., 1999), structure costs may increase up to 20% when an accurate ground response model can not be obtained. In the other case, if seismic response is underestimated, the designed structure may be incapable of withstanding seismic loads, increasing risk of structure failure and potential loss of life. In either case, the costs associated with inaccurate seismic response data can reach into the tens of millions of dollars. For this assessment, the cost–effectiveness of borehole geophysics is striking.

Surface Geophysics Cost Comparisons

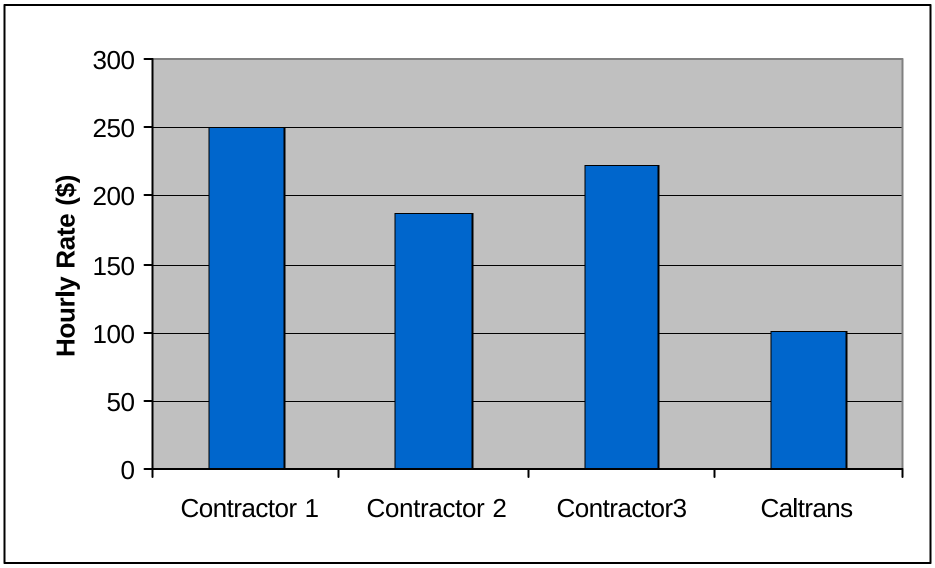

Figure 3. In-house versus contract costs to Caltrans for ground-penetrating radar field surveys, year 2000.

When evaluating cost for surface geophysical methods, it is important to remember that a primary goal for surface geophysical surveys is to minimize the number of holes drilled. Appropriate cost comparisons, therefore, can be made between drilling and geophysics, between in-house and consultant geophysics costs, and the costs of not having that data.

The one drawback I found in this research was that Caltrans does not have a significant database of surface geophysical contract costs. The reasons for this are twofold: 1) historically, most surface geophysical investigations for Caltrans were performed in-house (past demand was low enough for us to use existing staff), and 2) when geophysics work is contracted, it is typically performed under sub-contract, so only lump-sum figures are usually available. However, for ground penetrating radar (GPR), we found sufficient information to let us compare costs for field surveys. Our most recent data from three GPR investigations performed under contract yielded hourly rates ranging from $188 to $250 per hour, with an average of $220 per hour. Compared to our in-house data of $101 per hour, performing these surveys in-house can realize savings of 54% over the average contract cost (Figure 3).

When only in-house costs for foundation investigations are compared, the highest costs for data acquisition occur in drilling and laboratory testing. Caltrans' rate for drilling and laboratory analyses is approximately $15,200 per week. Assuming only seismic surveys (the most expensive geophysical method we perform) the cost to Caltrans for a fully staffed geophysical crew is $6,000/week. The comparisons are even more favorable on a per-project basis (Figure 4). Field costs for a typical drilling investigation are just over $22,800. A typical field geophysical survey costs Caltrans only $2,400. By judiciously using geophysics in conjunction

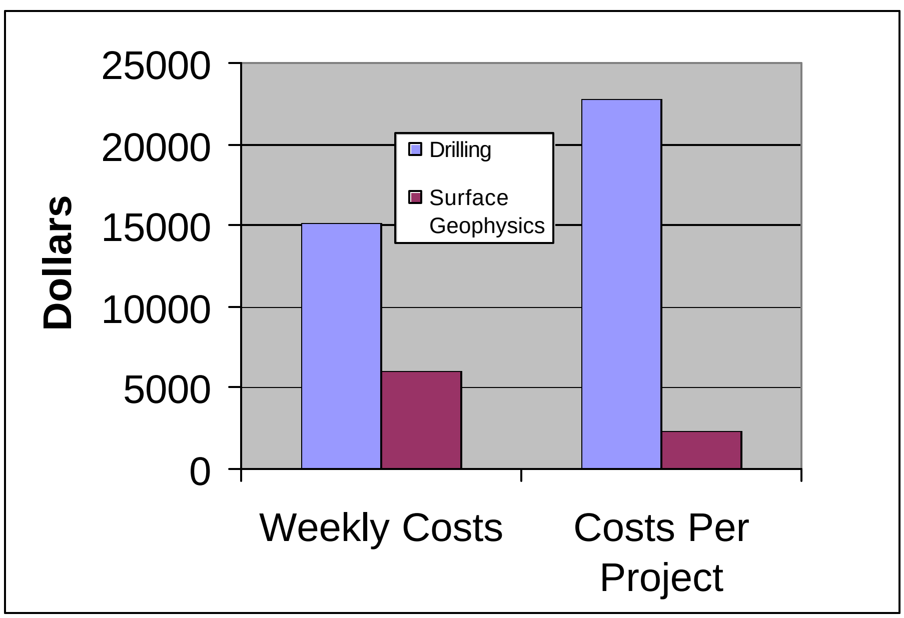

Figure 4. Comparison of in-house Caltrans field investigation costs for seismic refraction and drilling services.

with the drilling investigation, it is possible to reduce the number of holes for a given project. For the typical project, if just one borehole is eliminated via geophysics, the total cost to Caltrans for data acquisition is reduced 25%.

Consequences from lack of surface geophysical data vary with the type of project and with the geologic environment. In areas where geologic conditions are uniform over wide areas, like California's Central Valley, information provided by boreholes spaced hundreds of feet apart might be sufficient. However, in many areas of California, such as the Coast Ranges and the Sierra Nevada, geologic conditions vary dramatically over very short distances. In the Coast Ranges, for example, extremely large boulders can be encountered mere feet from boreholes that were boulder-free. Under those conditions, estimating bedrock depth, rippability, tieback anchor length or cut-slope inclination from borehole data alone is a perilous task, even for the most experienced practitioner. Using surface geophysics to extend borehole data substantially reduces risk of costly construction claims for changed site conditions and, at worst, redesign.

For large projects, cost savings can be significant. In one example, geophysical data recorded on the eastern abutment of a proposed bridge revealed a potential landslide that could impact the structure. This feature would not have been identified from the single hole drilled at that location. Although impossible to precisely quantify, having this information prior to construction reduced the risk of construction claims, project delays and repair costs related to instability of the abutment foundation, liabilities that could have easily reached into the hundreds of thousands of dollars.

SYMPATHETIC FACTORS

Cost-effectiveness was not the only factor that played a role in the expansion of in-house geophysical services. Simply being cheaper is of little benefit if there is no demand. Several factors came into play that resulted in increased demand for geophysical services.

The first (which, ironically, was initially instrumental in highlighting geophysics) was the completion of the Seismic Retrofit Program investigations. Because this program consumed so much of Caltrans' available engineering and geology resources (i.e., people and money), other highway construction, rehabilitation and maintenance projects were deferred. As the Seismic Retrofit Program began to wind down, those resources became available for other projects.

The second deals with Accessibility and the Familiarity Factor. Simply put, the Familiarity Factor is the tendency to cling to what we know. From a geotechnical investigation perspective, the Familiarity Factor can be defined as the tendency to do what's been done before. The Seismic Retrofit Program exposed a large number of engineers and geologists to the efficacy of geophysical methods. As those personnel moved on to other assignments, they tended also to request geophysics on those projects. Accessibility deals with the ease of access to goods and services, and the tendency to avoid acquiring those that are difficult to obtain. This observation is also true regarding geophysical services within Caltrans. When the project engineer or geologist was responsible for obtaining geophysical services through an outside contractor, the time and labor involved in securing those services through the contracting process limited access to those services. As those personnel familiar with geophysical methods became aware that the limited

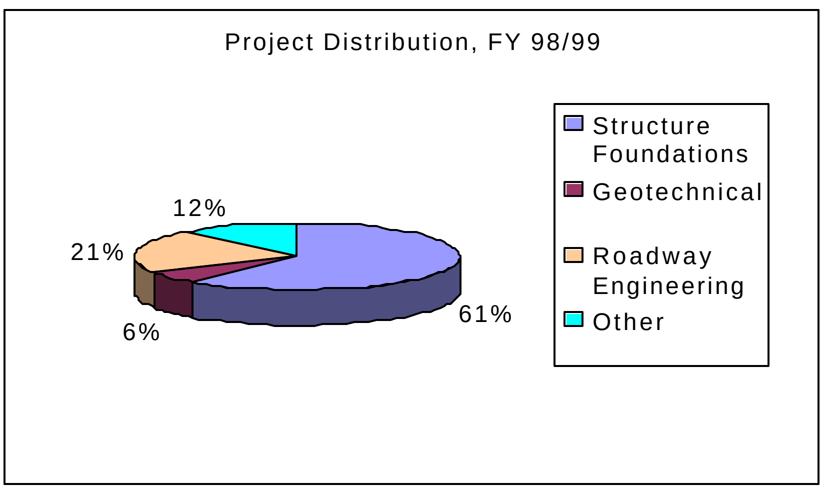

Figure 5. Geophysical services demand as distributed within Caltrans. The "Other" category includes maintenance, construction and environmental programs.

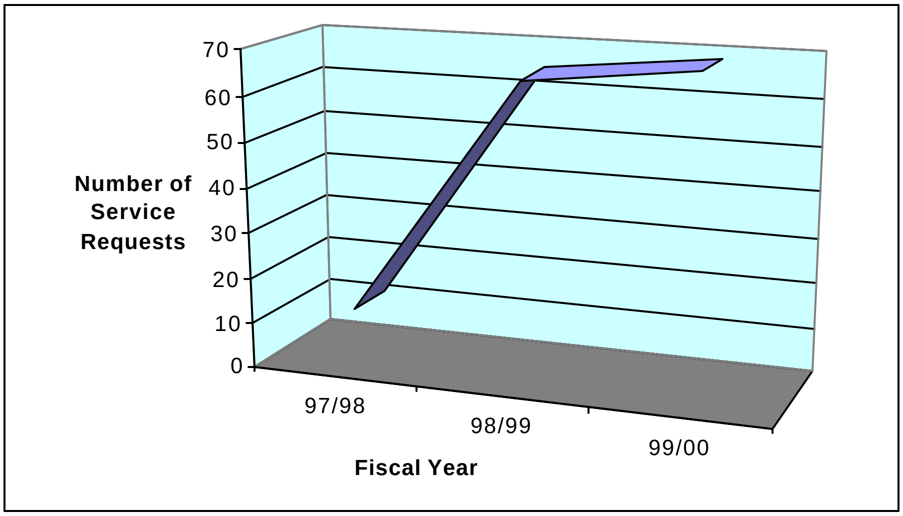

Figure 6. Increase in demand for geophysical services within Caltrans. 1997-2000

number of geophysics personnel previously assigned to the Seismic Retrofit Program were available for other projects, the number of requests for geophysics increased.

The final, and perhaps most important factor that came into play was the political climate in California. Between 1993 and 1997, Caltrans underwent a significant reduction in force, in spite of an increase in workload. The reduction in force was directed by an Executive Branch that was arguably ambivalent, if not hostile, to the role of the civil service system in California government. To make up for lost capacity, the Executive Branch directed Caltrans to increase outside contracting for services that were normally functions internal to Caltrans. This raised the ire of employee unions, and a lawsuit followed. In May of 1997, the State Supreme Court ruled in favor of the employee unions (Professional Engineers in California Government vs. Caltrans, 1997), essentially stating that a contrived force reduction could not be used to support contracting services normally performed by state employees. This ruling enforced existing state constitutional law that reserves outside contracts for instances where expertise does not exist internally, peak workloads temporarily increase demand, contracting is more cost-effective or the type of work is not of a recurring nature. For most geotechnical services required by Caltrans, including geophysics, those criteria are not satisfied, setting the stage for increased internal support of those services.

DEMAND FOR SERVICES

None of these factors would have made a difference, however, if a demand for geophysical services could not be documented. I started that process by assessing our client base.

Our main clients, by primary function, are responsible for structure foundations and roadway geotechnical engineering, with smaller demand from other offices (Figure 5). As a result of the factors just discussed, these offices experienced a dramatic increase in personnel. An increase in requests for geophysical work from those offices could be directly correlated to staffing in those offices, since an increase in personnel also increases project delivery capacity. In 1998/1999, the first year after the Supreme Court decision, demand for geophysical services increased 482% compared to the previous year, a figure that held steady the next year (Figure 6). This demand far exceeded the ability of the geophysical staff

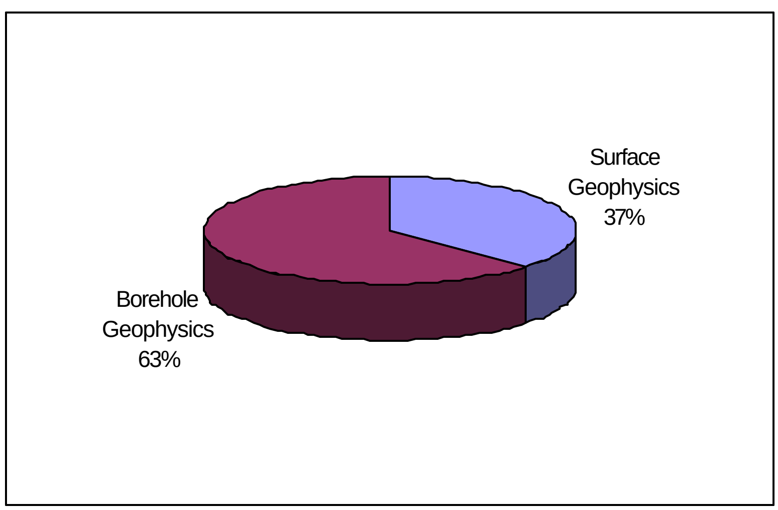

Figure 7. Distribution of Caltrans geophysical services demand by method, 1998/1999.

employed at that time to deliver on those requests. For example, the majority of our requests in 1998/1999 were for borehole geophysical logging (Figure 7). The controlling factor in the demand for geophysical logging is the number of boreholes constructed, which in turn is controlled by the number of drill crews in service. Historically, the maximum sustainable project delivery occurs with a logger-to-drill-crew ratio of 1:3 (That is, one geophysical logging crew for three drill crews). However, from 1997 to 1999, the number of drill crews in Caltrans increased by 233%, with no corresponding increase in geophysical crews. By the end of 1999, the logger-to-drill-crew ratio was 1:10, far exceeding our geophysical logging capacity. In addition, work demand for surface geophysical surveys, which are more labor intensive than borehole surveys, also increased (Figure 8). With this information in hand, we were able to convince Caltrans management that increased demand for geophysical services could not be met without an increase in personnel. In December of 1998, one additional geophysics position was authorized for the existing geotechnical support group in Caltrans. In July of 1999, work groups were reorganized and a Geophysical Services Unit, with a total of 4 positions, was created. In March of 2000, the unit increased again, to a total of 9 positions, a greater than four-fold increase in less than two years.

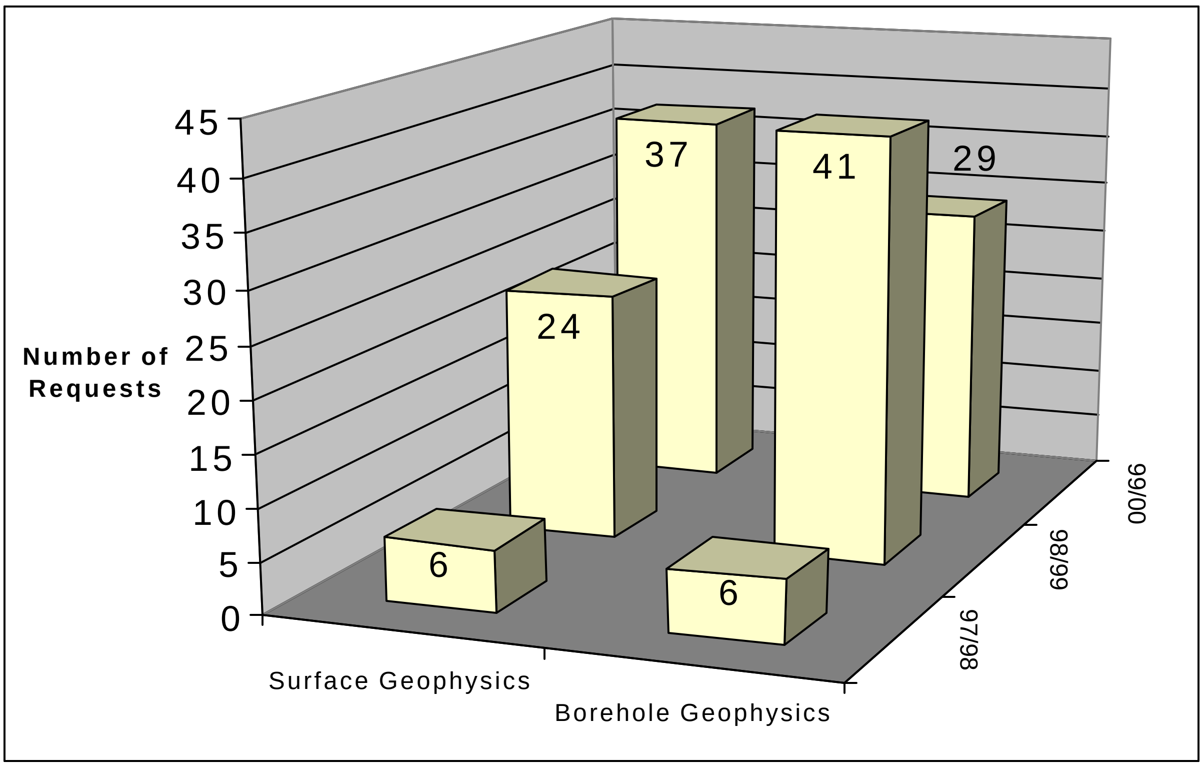

Figure 8. Requests for in-house geophysical services by method, 1997-2000. Increased requests for training are not shown. The decrease in borehole geophysics requests reflects a shift to larger projects (more holes per request) and does not imply a decrease in borehole geophysics demand. See text for more explanation. Note however, the increase in requests for surface geophysics. Since more personnel and field time are required for that service, that increase also reflects a significant increase in surface geophysics demand.

PARTING OBSERVATIONS

The process just discussed was not an overnight phenomenon. From the initial inception to its latest metamorphosis in March of 2000 took nearly five years. (For anyone else seeking a similar goal, patience is a positive character trait.) That period presented ample opportunity for learning experiences, some good, some less so. For those in state government interested in pursuing a similar course, some of my recommendations and observations can be summarized in the following paragraphs.

Know your market. Not everybody has the same problems. California has diverse geography, a plethora of engineering geologic problems and more seismic hazards than any other state. However, karst problems and frost heave, for example, though significant in some states, are non-existent in California. Any geophysical program, developed for any specific state agency, must be designed to address the problems particular to that state.

Create the need. In a perfect world, in my own humble opinion, everyone would clearly recognize the benefits of geophysical techniques and would gladly fork over large sums of cash, stand back, and let us work. Reality is far different. There, the proverb of the squeaky wheel holds true. As often is the case in government, response lags demand, and demand occasionally reaches urgent proportions before ameliorating measures are implemented. Caltrans is no exception. However, although we could not initially acquire personnel, we were able to build up our equipment inventory and offer additional services of value to our clients. Employing networking and marketing principles allowed us to maintain our client base and acquire new ones. The additional demand strained our workload, but also justified additional staff.

Document the demand. If you can't put it to paper, it doesn't exist. The need has to be concrete, genuine and specific. Be succinct. Spell out what is needed and propose solutions. Charts won't hurt. Use this documentation to sell your services to your decision-makers.

Get the commitment of upper management. This sounds obvious, but can't be over-emphasized. At Caltrans, we had a slight advantage in that we were not starting from scratch. We had a historical geophysical function, an existing equipment inventory and a commitment to maintain and upgrade that inventory. In our agency, where we spend tens of millions of dollars on equipment each year, the amount of funds expended obtaining geophysical equipment makes no dent in the balance sheets. However, the long-term costs of full-time, permanent employees are not insignificant, and that is where the budget authorities had to commit to ensure long-term program funding. Convince your management that what you offer is worthwhile.

Capitalize on serendipity. Everybody gets lucky occasionally. For example, some of our most interesting jobs came through the office grapevine. Take advantage of opportunities to offer your services, be it as a direct provider or as a project manager. If a project engineer or geologist has a project budget that allows procurement, we've had some success bartering work in exchange for equipment. If the work is to be out-sourced, using your geophysical background as part of a quality team review will assist in obtaining an acceptable end product.

Don't ignore the political climate. Finally, if you work for the government, everything is political. Even the best of ideas will be doomed if it runs counter to legislative or executive mandates. Being in a scientific field and accustomed to logic and order will be of little help: the fields of human endeavor are anything but logical. Each state has slightly different regulatory requirements that govern the mix between contract and in-house work, with roughly half of all states outsourcing 50 percent or more of their investigation and design work. This outsourcing is expected to increase, primarily due to increased infrastructure demand for those services and a desire by states to limit or cap growth of in-house staff (Kaye and Kreutzen, 1999). An in-house geophysics program may not be feasible for every state, and in some it may not be warranted, especially in small states with low to moderate geophysics demand. In that case, an oversight function of out-sourced geophysical work may be a better fit. Presenting your case in a manner favorable to the current political atmosphere may meet with success. As we found in California, cost-competitiveness and construction savings provide a strong rationale for providing geophysical services. That argument applies both for in-house and out-sourced geophysical services.

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