AN OFFSHORE GEOPHYSICAL SURVEY IN SUPPORT OF A HIGHWAY RECONSTRUCTION PROJECT, WASHINGTON

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Under the direction of the Washington State Department of Transportation (WSDOT), a major highway reconstruction project is in preliminary design phase along a 12-mile section of Interstate 90, east of Snoqualmie Pass, Washington. The project will address substandard horizontal and vertical alignment, mitigate for winter avalanche conditions, and add additional lanes to the facility. The western most segment of this project consists of a three-mile section of highway that is severely confined by steep terrain to the northwest and by Lake Keechelus to the southeast. To determine the best alignment through this section of the project an offshore geophysical survey program and selected test-boring program was performed. Over 100 miles of geophysical data were obtained with a digital echosounder, sidescan sonar, and high-resolution seismic reflection systems during a four-day period. The data were used to develop a bathymetric map of the steep slopes, map the thickness and lateral extent of unconsolidated sediment, identify bedrock outcrops, locate evidence of previous submarine slides, and identify areas of potential slides. The offshore geophysical data, together with the borings, has provided a cost-effective means for designing and selecting the location for the placement of embankments, retaining walls, and bridge structures in this extremely difficult section of highway.

INTRODUCTION

The Washington State Department of Transportation (WSDOT) is proposing to reconstruct a four-mile section of Interstate 90, immediately east of Snoqualmie Pass, Washington (Figure 1). The project would address substandard horizontal and vertical alignments, mitigate for winter avalanche conditions at five locations, and add two additional lanes to the existing four-lane interstate highway facility.

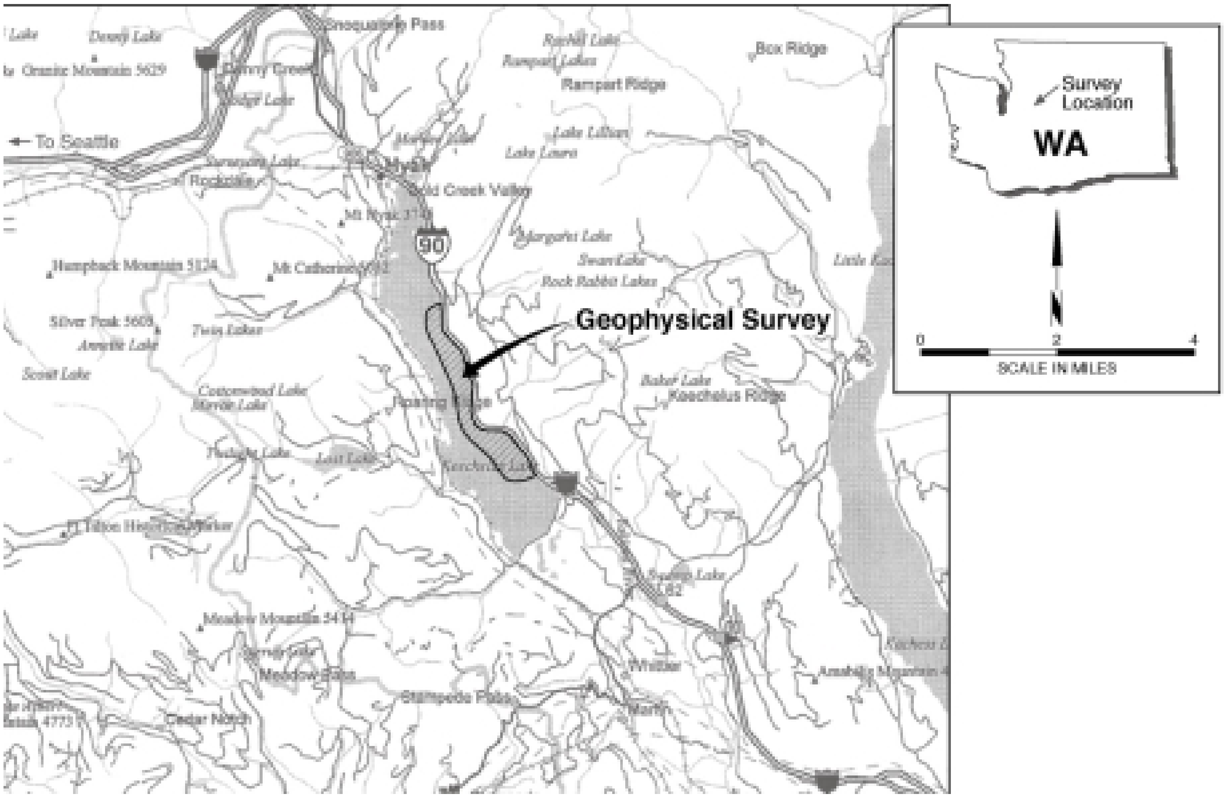

Figure 1: A comprehensive offshore geophysical investigation was conducted along the northern shore of Lake Keechelus to assist in determining the best alignment for I-90 reconstruction.

The new section of highway will be located along a steep embankment that is the north shore of Lake Keechelus. It was evident that it would be extremely difficult to develop a clear understanding of the surface and subsurface geology on the steep slope based on a few borings. It was decided that the most cost effective means to obtain critical information was with the use of offshore geophysical techniques (Sylwester and Anderson, 1997).

The specific goals of the offshore geophysical investigation were to:

- Develop a bathymetric contour map of the slope and lakefloor.
- Map the surficial sediment, bedrock exposures, and submarine slides.
- Determine the thickness of sediment deposits, depth to bedrock, and identify possible geohazards.

Site Conditions

The project area is located three miles east of the Snoqualmie Pass summit. In this area the highway traverses the northeast shore of Lake Keechelus and is severely confined by steep mountainous terrain to the northeast and by Lake Keechelus immediately to the southwest.

The highway alignment has been cut into the steep bedrock slopes along the northeast shore of Lake Keechelus. In a few areas, along the existing alignment, steep rock embankments in excess of 100 feet in height have been constructed into Lake Keechelus. At least six avalanche paths are present along the project corridor. An existing snow shed, which was completed in 1950, covers two of the westbound lanes, and serves to partially protect the highway form two avalanche paths. The remaining avalanche paths are controlled during the winter months with the use of explosives.

A geotechnical investigation was initiated as part of the preliminary design effort to select the best alignment through this section of the project. The intent of the geotechnical investigation was to provide the project design team with preliminary geologic and geotechnical data from which viable highway alignment cost estimates and benefit cost analysis could be generated. The investigation was multi-phased and included subsurface drilling, rock structure mapping, and geophysical and bathymetric survey to provide site characterization along the northeastern shore of Lake Keechelus.

GEOPHYSICAL METHODOLOGY

Acoustical techniques provide a cost effective means to investigate and map surface and subsurface sediment and other geologic features offshore (Sylwester, 1983; Sylwester, et. al., 1997). This investigation used a combination of three common acoustical methods; precision echosounding, sidescan sonar, and continuous seismic reflection profiling, to achieve the project objectives (Figure 2).

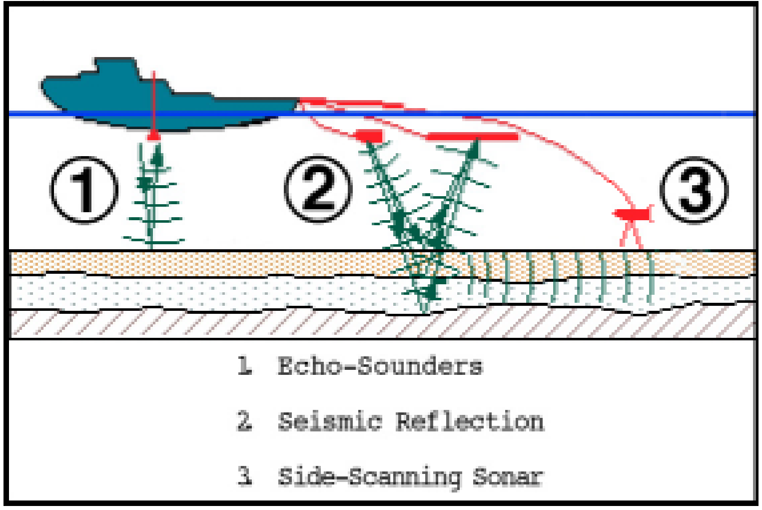

Figure 2: The geophysical investigation used three acoustical methods to map the surface and subsurface geology in the survey area. The data from all three systems was acquired and displayed in real-time as the survey vessels travels approximately 3 to 4 miles per hour.

General Operation Considerations

The three primary components to consider when planning an offshore geophysical investigation are the survey vessel, the navigation system and the method of remote sensing. The size of the survey vessel, the type of navigation system, and the method of remote sensing. The size of the survey vessel, the type of navigation and type of sensors depends on the projective objectives, scale of the survey and the location of the study area (ocean, river, lakes, etc.). This paper is an example of a typical offshore investigation that can be conducted from a small survey vessel (15 to 30 feet), using readily available navigation and geophysical equipment that generally provides excellent information at a reasonable cost.

Survey Vessel

The survey vessel for this project was a 22-foot aluminum boat with a jet drive. The boat was towed to the site from Seattle and the equipment was installed and tested prior to beginning the survey. The field crew of three people was able to mobilize the survey vessel and equipment in 1 day. No special boat is required for this type of operation hence they can be readily rented or leased in most places for a cost that might range from 100.00 to 500.00 dollars per day. We have successfully conducted this type of operation from a 15-foot inflatable that was transported to a remote site in the Arctic and was moved between a number of lakes by slinging from a helicopter.

Navigation

Most offshore surveys now use the global positioning system (GPS) for determining the survey vessel position. The GPS navigation system uses a small receiver to obtain information from a network of satellites to determine the position of the vessel while underway with an accuracy of approximately +/- 100 feet. For most surveys, this level of accuracy is inadequate and to gain substantial improvement it is necessary to use differential GPD. With this method, the GPS receiver on the vessel obtains correction factors from a US Coast Guard receiver station or from a receiver place on a shore monument or on some location with know co-ordinates. The shore-based station (Coast Guard receiver and beacon or temporary receiver and beacon) determines the difference between their known location and what the satellite indicates is their location. This differential is transmitted to the receiver on the survey vessel and the vessel position is corrected in real-time resulting in a position accuracy of approximately +/- 10 feet or better. Post-processing of the position data can achieve accuracy on the other of +/- 6 feet to 10 inches or better.

During the survey a navigation program plots the desired survey trackline (preplotted transects) and the actual position of the survey vessel as determined with dGPS. This information is displayed on a computer screen or a video monitor that is used by the boat operator to drive the vessel along the selected transects. The information is updated at least every second and digitally recorded so that the tracklines can be plotted and used during data analysis.

Differential GPS receivers can be rented for approximately 100.00 per day. These receivers will digitize and store the navigation and bathymetric data. They usually are provided with a simple navigation package that can be upgraded with a more sophisticated software program if needed. This usually costs 50.00 to 100.00 per day and may require some training.

Precision Echo Sounding

An echosounder is used to obtain very accurate measurement of the water depth. The data is obtained with a small, high frequency transducer (100 to 200 kHz typical), attached to the survey vessel, which can resolve very small changes in the relief of the lake floor (+/- .03 feet). The data is usually displayed on a graphic recorder and simultaneously acquired digitally on the navigation computer. This equipment is battery operated and can operated from almost any size of survey vessel. A survey-grade echosounder rents for 75.00 to 150.00 per day and requires some training and understanding regarding calibration, monitoring water elevation, and post-survey editing of the data.

Sidescan Sonar

Sidescan sonar produces a plan view image of the lake floor or seabed to either side of the survey vessel trackline. The sidescan sonar transducer or tow fish is deployed from the stern of the vessel and lowered until it is approximately 30 to 50 feet above the bottom (Figure 2). As the survey vessel moves along the track line the sonar transmits a fan-shaped acoustical signal. The narrow portion of the fan shaped signal is perpendicular to the tow fish or to the survey trackline. Each time the transducer transmits an acoustic signal it “paints” a very thin picture of the lakefloor to either side of the transducer. These thin slices are continually plotted on a graphic recorder as the survey vessel moves along the trackline so that eventually an acoustic photograph of the lake floor is produced. This image can be obtained and displayed in real-time at speed of 4 to 5 miles per hour. The full width of this image, which is controlled by the operator, typically ranges from 150 to 500 feet.

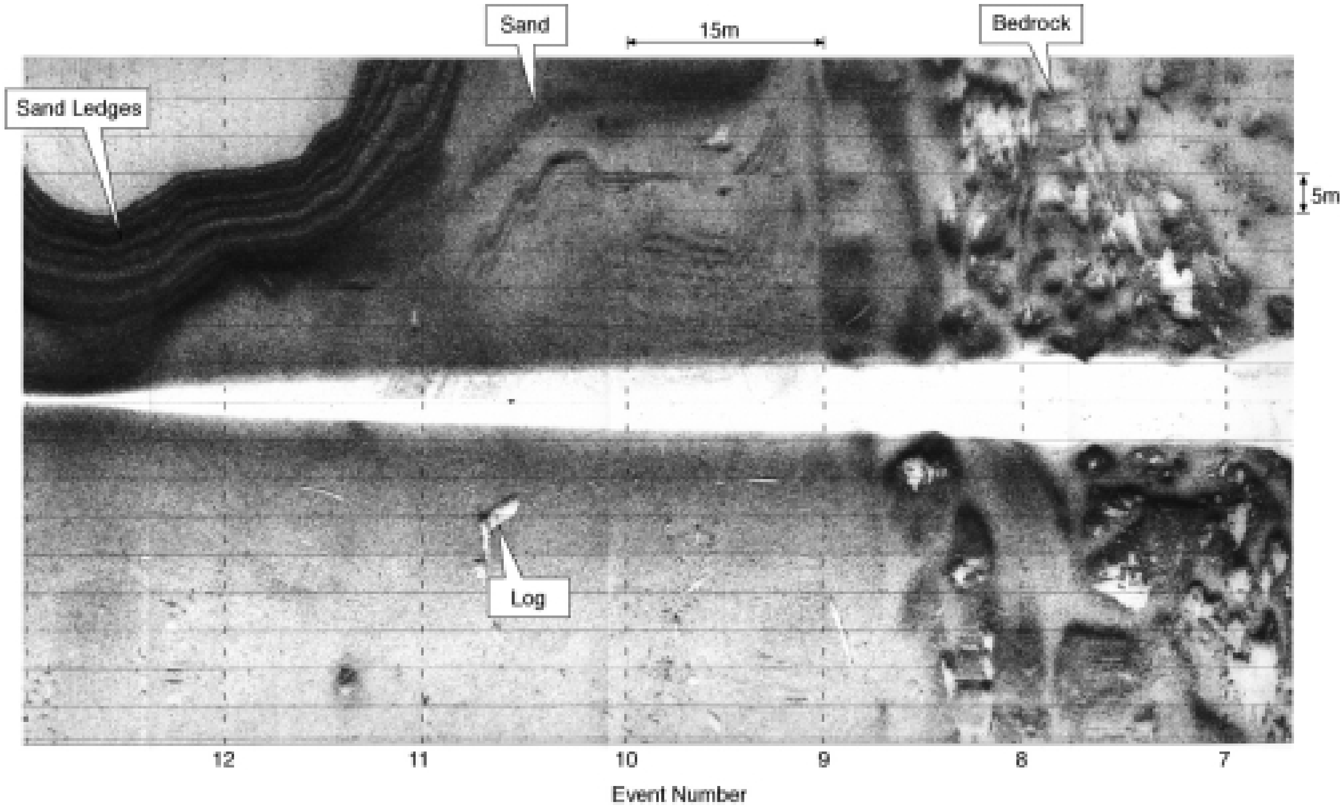

Figure 3: A sidescan sonar image along a section of the shoreline. This plan view image, similar to an aerial photograph, clearly shows the variability in material on the lakefloor.

The sidescan sonar record is a variable density image (similar to a photograph) where the range from black to white represents the mound of acoustic energy that is backscattered (a special form of reflection) from the lake floor. Fine-grained sediment, such as silt or clay, backscatters a small amount of acoustic energy and is characterized by a uniform light pattern. An increase in grain size results in an increase in backscattered energy and an increase in the darkness of the image on the sonogram. Rock outcrops or surficial features such as sunken vessels, cables, pipelines, etc. produce a very dark image and have an acoustic shadow (white zone) behind them. The use of color to represent the variation in backscattered energy greatly improves the ability to interpret subtle variations in texture and material type.

A sidescan sonar costs 250.00 and 350.00 per day. In shallow water environments, they do not require special handling equipment, such as winches, however the acquisition and interpretation of the data requires a skilled operator and interpreter.

Continuous Seismic Reflection Profiling (CSRP)

This acoustic method is used to image features below the lake floor or seabed. The CSRP system produces acoustic pulses or sound waves with a transducer towed astern of the vessel that are transmitted two to four times/second. The acoustic pulse travels through the water column and upon contact with the water –sediment interface some of the energy is reflected back toward the surface. The remaining energy travels through the water-sediment interface (ignoring scattering effects) into the underlying material. At the next interface or boundary, which will be between two sediment layers with different physical properties, the process is repeated. The amount of energy that is reflected at, or the amount transmitted through, the interface, depends on the relative change in the density and velocity of sound and the material on either side of the interface. If there is a large contrast in density and velocity at the interface (water to bedrock) nearly all the energy is reflected back to the surface and very little, if any, subsurface information can be obtained. For a small relative contrast (water to silt) very little energy is reflected and most of the energy is transmitted through the interface to be reflected where the next relative change in velocity and density occurs. It is quite common to achieve several hundred feet of subsurface penetration in medium-grained sediment with small seismic reflection systems.

The reflected energy is received at the water surface by a hydrophone, also towed astern of a vessel, which convert the acoustic energy to an electrical signal. The electrical signal is processed by an amplifier and printed in real-time on a graphic recorder than displays a continuous cross-section image of the subsurface along the source trackline. At a typical survey speed of 3 knots (approximately 3 miles/hour) a subsurface reflection record is obtained every 2 to 3 feet of travel along the trackline.

A seismic reflection system costs 250.00 to 400.00 per day. They do require a skilled operator, and the selection of the appropriate type of reflection system for the anticipated geologic conditions to achieve success.

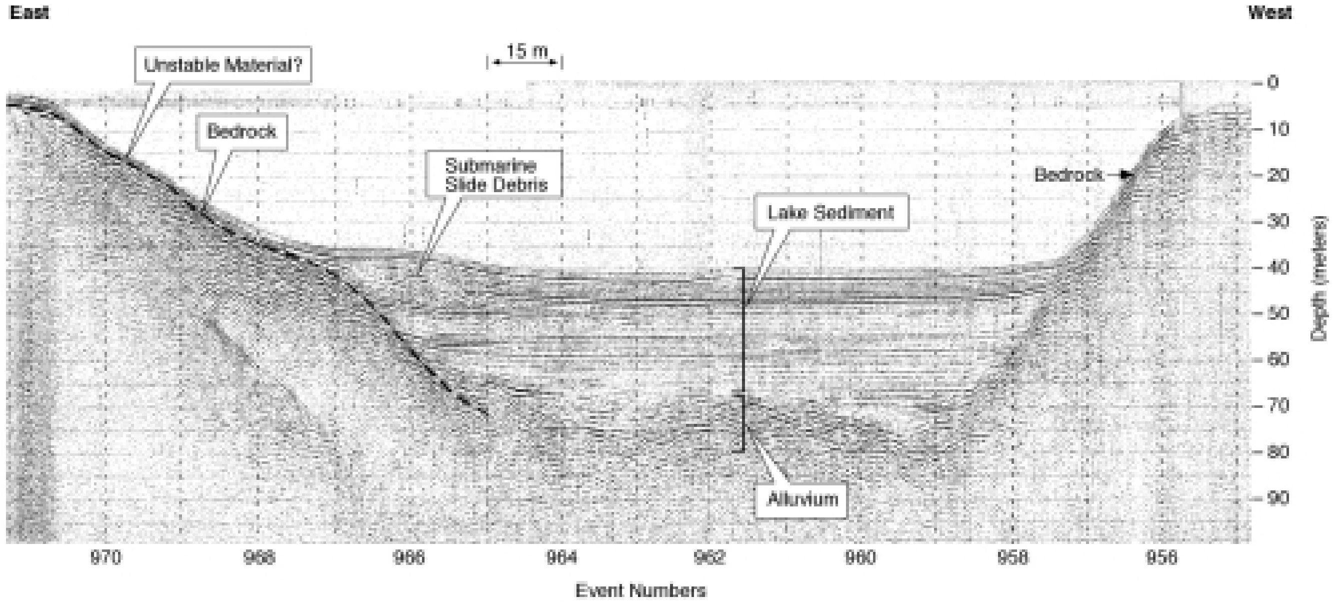

Figure 4: A continuous seismic reflection record across Lake Keechelus as it appeared in real-time on the graphic recorder during the survey. This image, acquired in 5 minutes, clearly illustrates the capabilities of small reflection systems.

INTERPRETATION

Survey Coverage

A series of transects, on which all three acoustic systems were operated simultaneously, were run parallel to the shoreline along the 3-mile length of the survey area. A second set of transects was run perpendicular to the shoreline extending from waters edge to 1000 feet offshore. The maximum interval between transects was 200 feet. However, in critical areas this was reduced to 50 feet.

During data analysis a series of trackline maps were produced which showed event numbers (20 second time interval) along each transect. These numbers corresponded with numbers that were annotated on the acoustic records by the navigation system during the survey.

Bathymetric Data

The detailed bathymetric data, which was edited and displayed as a contour map, clearly showed very complex slope and lakefloor conditions. Irregularities in the contours were interpreted as possible evidence of submarine slope failures, exposed bedrock knobs, and rock collapse features.

Sidescan Sonar Data

The sidescan sonar transects along the shoreline, steep slope and lakefloor produced images that showed the complexity and variability even more clearly and dramatically than shown by the bathymetric data (Figure 3). The interpreted data were plotted on a plan view map that used different patterns to represent the interpreted geologic features. These features included the location and extent of submarine slides, boundary of rock outcrops, lateral boundaries of various sediment types (silt, sand, and gravel, slide debris).

Continuous Seismic Reflection Profiler Data

The seismic reflection data supported the observations and interpretations that were made based on the bathymetric and sidescan sonar data. In addition, it was used to identify and map areas of possible impeding slope failures, to determine the thickness of the various sediment units and to map depth to bedrock in critical areas. Figure 5 shows a typical example of subsurface conditions at the base of the slope.

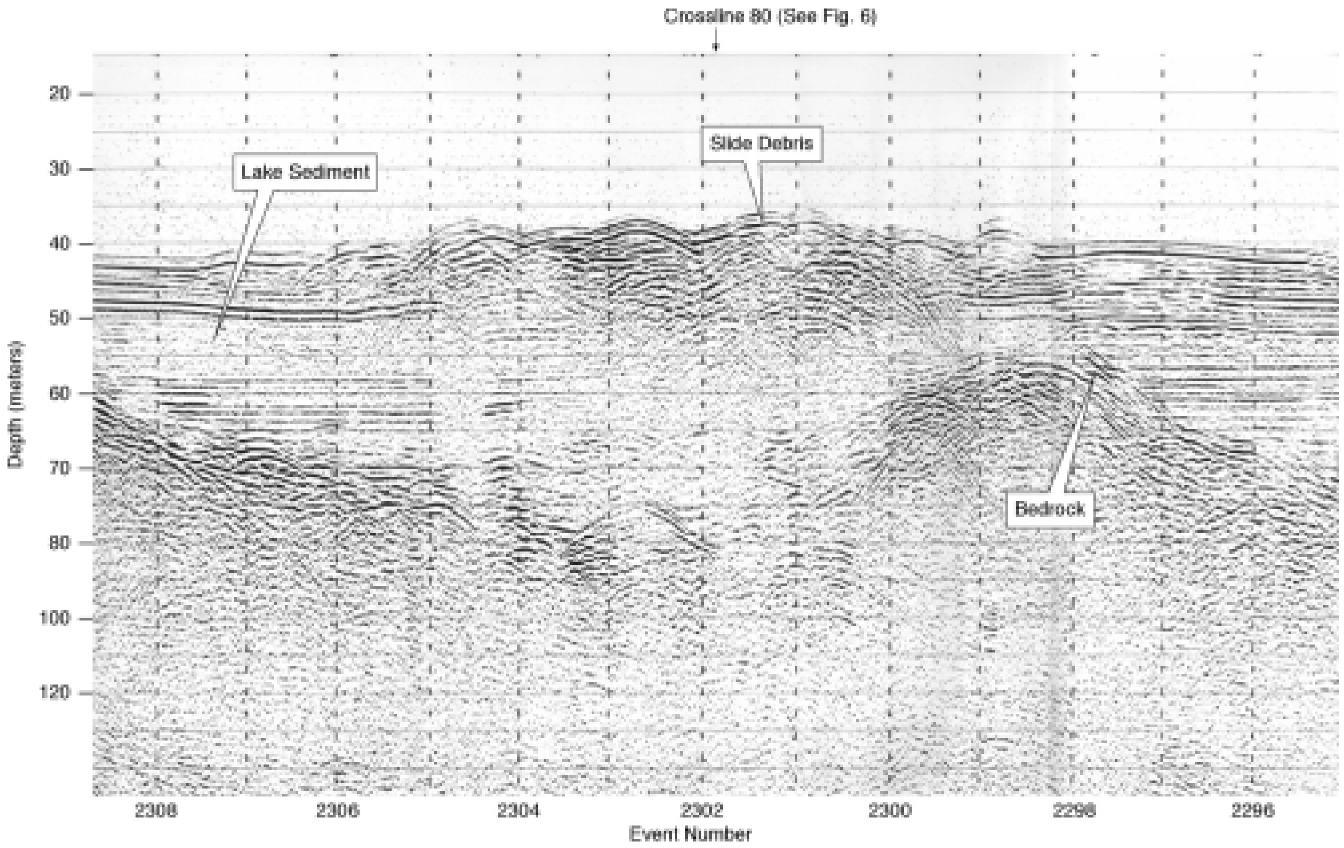

Figure 5: A seismic reflection profile parallel to the toe of the steep slope. This information, together with sidescan sonar and bathymetric data was used to produce detailed maps of submarine slides and other geohazards that could impact the project.

DISCUSSION

The geophysical investigation was able to map a relatively large and geologically complex area in a short period of time. The survey took four days during which time the detailed bathymetric and side scan sonar survey was able to provide nearly 100% coverage of the area. The seismic reflection program was adjusted on the field, based on preliminary interpretation of the sidescan sonar data. Paper copies of all the data were available in the field, as well as trackline plots, making it possible to discuss recommended changes to the program with WSDOT.

The final report completed within 2 weeks of the field program contained contoured bathymetric maps, surficial features maps based on interpretation of the side scan sonar data, and selected scanned images of the seismic reflection data. In addition, copies of all of the sidescan sonar and seismic reflection data were bound with a set of trackline maps so that WSDOT could evaluate other alternatives.

When planning an offshore geophysical investigation it is extremely important to clearly define the objective and the desired deliverables and to provide the survey team with all available data regarding site conditions. All three of items can have a significant effect on the success of the geophysical investigation since they determine the design of the survey grid, the selection of equipment and the data analysis and processing procedures.

SUMMARY

During the design definition phase for this major project, along a difficult and highly constrained portion of Interstate 90, an innovative approach to the geotechnical site characterization was imploded. The use of widely spaced test borings, geologic mapping, and geophysical and bathymetric surveys provided a reliable, accurate, and cost effective means to provide high quality geotechnical data to the project design team.

The preliminary geotechnical and geophysical data enabled the project team to make appropriate decisions in the project definition phase of the design to identify geotechnical flaws with the early alternative alignments. Additionally, the geotechnical and geophysical data will be utilized as “building blocks” for future more detailed geotechnical investigations as this project moves forward into final alignment selection, environmental analysis, and final design.

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LIST OF FIGURES

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