Marine geophysics as a risk management tool



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ABSTRACT

Marine geophysics is frequently used as a risk management tool when constructing and maintaining structures within marine environments. The geophysical methods most frequently used are sub-bottom profiling, bathymetry, and side-scan sonar. This paper briefly outlines how these methods can be used to manage risk in three cases, a riverbed scourhole problem near a bridge, a mining engineering application, and a harbor construction application.

RÉSUMÉ

La géophysique marine est souvent utilise comme outil de gestion de risques lors de la construction ou de l'entretien d'infrastructures en environnement marin. Les méthodes les plus couramment utilisées sont celles de profilage, bathymétrie et sonar à balayage latéral. Cet article décrit brièvement chacune des méthodes et présente trois histoires de cas où ces méthodes ont été appliquées : sillon d'érosion dans le lit d'une rivière près de piliers de pont, une application pour un ouvrage de génie minier et finalement une étude de site portuaire.

1 INTRODUCTION

Among the problems that engineers face during the construction of structures in marine environments is estimating the cost of securing the structures to solid ground such as bedrock. Boreholes are drilled for that purpose but the cost of drilling in a marine environment is often one order of magnitude higher than drilling on land. Geophysics can be a useful tool for solving this problem by helping to give the engineer an indication of the depth to bedrock, the hardness of the bedrock and the overburden, information about some of the possible obstacles that may be encountered on the water-bottom. This paper discusses how marine geophysical methods can be used to help manage marine construction projects and to help reduce the risks associated with the unknown conditions of the sub-water-bottom.

2 METHODS

2.1 Sub-Bottom Profiling

The sub-bottom profiling method involves creating a medium frequency sound wave (200 Hz to 16 KHz) at the water surface and recording the sound that has echoed off of the layers beneath the instrument. Echoes are created where the sound wave travels across a seismic impedance contrast. Seismic impedance is the product of the seismic velocity and density of a material. The relative strength of the reflection is dependent on the reflection coefficient of the two layers according to the following equation:

$$R = \frac{Z2 - Z1}{Z2 + Z1}$$

Where: R = reflection coefficient, Z1 and Z2 are the impedances of the two layers.

Typical reflection coefficients for geologic interfaces normally encountered in marine surveys are shown in Table 1.

The choice of frequency for this method depends on the requirements of the survey; higher frequencies give better resolution but poorer exploration depths, and lower frequencies give poorer resolution but greater exploration depths.

Table 1:	Typical	reflection	coefficients	(modified	from
Sylwester	r, 1983)				

Oymcolci, 1000/		
Material	Reflection Coefficient	
Water/air	-1.0	
Water/limestone	0.5	
Water/sand	0.3 - 0.4	
Water/clay	0.1 – 0.2	
Water/mud	0.05 - 0.1	
Mud/clay	0.1	
Clay/sand	0.1	
Sand/limestone	0.2	
Clay/limestone	0.3	
Sand/granite	0.4	

2.2 Bathymetry

Bathymetry data is collected using either a singlebeam or multi-beam fathometers, depending on the scale of the project. A single beam system produces a high frequency sound wave from a transducer at the surface, which is reflected off of the water-bottom and detected by the transducer. Taking the travel-time of this signal and the speed of sound in water (1500 m/s), a water-bottom depth is calculated. Because of the high frequency of the sound wave produced (100-200 KHz), the accuracy of water-bottom measurements are typically in the range of \pm 0.03 m, but the signal cannot penetrate the water-bottom.

2.3 Side-Scan Sonar

The side-scan sonar method uses wide angle bathymetry to efficiently image large areas of the water-bottom on either side of the survey device. It operates in a similar fashion to traditional fathometers, which are narrow-beam depth-sounders. The side-scan sonar system directs sound waves from a transducer suspended beneath the instrument in a fan shape towards the water-bottom. Reflections are recorded to provide an image of the water-bottom to the left and right of the instrument's path as seen in Figure 1.



Figure 1. Schematic of side-scan sonar system.

(source:http://woodshole.er.usgs.gov/operations/sfma pping/images/sonartracktextnotow.jpg)

3 SAMPLE CASES

3.1 Riverbed Scour-Hole Detection

One of the risks facing bridges is the formation of riverbed scours at the base of their support pillars. These riverbed scours are one of the major causes of bridge collapse throughout the United States (Murillo, 1987). Scour-holes can develop during periods of high flow, and then can fill in with unconsolidated sediment during periods of low flow (Trent and Landers, 1991). These filled-in scours cannot be easily distinguished from the surface.

Recently, AGL conducted a survey to detect scourholes around a bridge in southern Alberta. The survey started with side-scan sonar and a bathymetric survey. A sample side-scan sonar section from the survey is displayed in Figure 2. The scour-holes appear as shadows near the bridge pillars.

The bathymetric data was complied and contoured and a map of the water-bottom elevation is presented in Figure 3. The scour-holes are clearly visible at each bridge pier.



Figure 2: Sample side-scan sonar section, showing surface scour-holes near bridge piers.



Figure 3: Water-bottom elevation map showing scour holes around bridge piers.

For sediment-filled scour-holes, the side-scan sonar section might show subtle changes, but cannot be reliably used to map them. There will be a density contrast between the sediment that is filling up the holes and the water-bottom material. Sub-bottom profiling (marine seismic reflection) was used to map these filled in scour-holes. Since sub-bottom profiling surveys generally employ a single source and a single receiver, the survey must be conducted in a grid pattern with relatively tight line spacing. Sample sections showing filled in scour-holes are presented in Figures 4 and 5.



Figure 4: Sample sub-bottom profile showing a sedimentfilled scour hole near a bridge support.



Figure 5: Sample sub-bottom profile showing two filled in scour-holes.

3.2 Mine Engineering Application

There are many mining operations in Canada that are conducted beneath lakes. In this case study, a drift was planned beneath a lake but there were concerns about major disruptions in the bedrock that would negatively impact the development of the drift. A marine seismic reflection survey was designed to map the water depth, thickness of underlying sediments, bedrock surface and structure within the bedrock. A land seismic refraction survey was also conducted to provide information in the shallow water transitional zone.



Figure 6 shows a typical seismic record from the geophysical investigation illustrating the direct arrivals, refraction arrivals and reflectors.

On the lake, a sub-bottom profiler survey was conducted to collect seismic reflection data to profile the bedrock along the proposed axis of the drift. An interpreted seismic section is shown on Figure 7. There is a significant variation in bedrock topography with a deep trench clearly visible sub-parallel to the major axis of the lake.

The combined data set (seismic refraction near shore and seismic reflection offshore) was processed in two phases. In the first phase, the velocity of the water and underlying sediments was assumed to be 1500 m/s . Once drill hole data became available, the seismic reflection data were re-processed using a velocity of 1500 m/s for the water and a velocity of 1800 m/s for the underlying sediments. Correlation with drilling is an extremely important part of the interpretation if accurate depths to bedrock are required. The final map showing the elevation of the bedrock surface as mapped by the integrated seismic reflection results and drill hole data is shown in Figure 8. Once again the deep trench that is sub-parallel to the major axis of the lake is clearly visible.



Figure 7: Typical interpreted seismic reflection section along the axis of the proposed drift



Figure 8: Map of bedrock elevation based on seismic refraction, seismic reflection and calibrated with drill-hole data.

3.3 Harbour Construction Study

This case history presents a harbour project in a remote Canadian location for mining operations. Figure 9 shows the outline of the site in arctic waters.

The objective of the survey was to map water depths and depths to bedrock up to the 30 meters water depth isocontour line. A bathymetry and sub-bottom profiler survey was conducted on a dense grid over the entire area. An example seismic record is shown on Figure 10 below.



Figure 9: Outline of the survey area

Although the water bottom reflection appears on the seismic record, the bathymetry data was recorded independently of the seismic with a depth sounder for a better accuracy as required for navigation purposes. The data was presented as profiles every 5 meters from shore for construction design as well as contour maps as shown on Figures 11 and 12 below.









Figure 12: Sediment thickness isopach map



Through a series of case histories, we have shown how marine geophysical investigations can help reduce risk in the planning, design, construction and monitoring phases of engineering projects. Each geophysical method has its own set of limitations and the limitations need to be clearly presented to the engineer so that the engineer has a realistic view of what can be anticipated from the survey results.

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