Why multi-frequency approach on shallow water seismic investigation?

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Abstract

Seismic profiling is a well-known geophysical method for underwater geological and geotechnical investigation Bathymetric surveys are applied when the project needs information about the thickness of water column. Waterways, harbors and reservoirs are examples of environments that necessitate this kind of data. On the other hand, if images from bottom surface become important information for certain projects, a side scan sonar or even a multibeam echosounder system can play an important role in the underwater investigation process. However, if data from subsurface should be available for the project, continuous seismic profiling methods must be applied. When talking about seismic profiling we should discuss many types of seismic sources, from the ones which operate with low energy and a wide range of frequencies (3 to 20kHz) like chirps and the classical sub-bottom profiler (SBP), to the ones which deal with high energy like boomers and sparkers. Actually, in certain projects, is not simple to choose the right seismic source for sub-bottom profiling. Some recent field experiences have shown that using a large spectrum of frequency, from 500Hz to 500kHz, simultaneously, seems to be the best way for shallow underwater investigation in order to get the best and suitable final product.

Introduction

Seismic has been a well-known geophysical method for shallow water investigation for many years (Jones, 1999; Souza, 2006; Atherton, 2011; Fish, Cara & Arnold, 1990 & Blondel, 2009; Mosher & Simpkin, 1999). Building of harbors, waterways and dams, as well as dredging, landslides and outfall projects are examples of activities where seismic profiling is used to support making of important decisions (Souza, Alameddine & Iyomasa, 2010; Souza, Alameddine, Yassuda, 2011; Ianniruberto, Campos & Araújo 2012; Vardy et al. 2012).

High frequency systems usually are good for mapping the surface. This group includes seismic equipment utilizing frequencies usually from 50 to 1000kHz, or even more. Bathymetry (single beam or multibeam) and side scan sonar systems are the main tools in this group (Souza & Gandolfo, 2013; Souza, Miranda Filho, Mahiques, 2008; Souza, Silva & Iyomasa, 1998; Souza, et al, 2007; Souza, 1988).

On the other hand, low frequency systems are applied for sub-bottom mapping, sometimes getting data from shallow interfaces (shale/sand strata), sometimes from deep ones (bedrock), depending upon the range of frequencies used (Souza, 2006).

Boomers, sparkers and high energy chirps are the most common seismic source included in this category. Operating at frequencies as low as 500Hz, and usually not higher than 2kHz, these seismic sources make it possible to get seismic profiles with information up to more than 100m deep, in some cases.

Low energy and high frequency systems like chirp and classical SBP offer high resolution products and make it possible to characterize shallow sediment strata to within a few centimeters in thickness.

Method

Seismic methods are commonly applied for underwater shallow investigation all around the world, but usually most of the surveys utilize just one seismic source. There are, at least, three reasons for that: 1) the company has only one seismic source to offer to the contractor; 2) they suppose, in advance, they will need only information from shallow strata or the opposite, never both. Sometimes they suppose they need data only from the bottom surface, not from the sub-bottom. This decision can lead to big mistakes.

The purpose of this article is to show that even in the case that a project needs only information from very shallow strata (e.g., dredging, outfalls projects) or data from the bottom surface only (e.g., waterways, search & rescue projects) data from the deep strata or about the bedrock depths, just as an example, could help a lot in some unpredictable but valuable way.

Keeping in mind that one should always strive for the best final product from a seismic survey, we could conclude that we must run, simultaneously, a broad range of frequencies (e.g., from 500Hz to 1000kHz). This range of frequencies include bathymetric, side scan sonar and continuous seismic profiling surveys. This combination can provide both penetration and resolution at the same time with a good cost-benefit ratio. Besides, most projects nowadays require both high resolution and penetration on the final products from a seismic survey.

Actually, when using a side scan sonar, bathymetric and continuous profiling system at the same time, one generates a data set that makes it quite easy to build the geologic model of the study area. The possibility to interpret a group of profiles from different seismic sources running on the same line, as shown on Figure 3 and Figure 4, and also on Figure 5, make it possible to gain a more complete picture of the geology of the studied area. This information is of indisputable value for most of the projects.

The digital systems nowadays allow us to install a bathymetry system, a side scan sonar, a chirp and a boomer system, all in the same boat, and also makes it possible to run all systems simultaneously, under a synchronized firing process. A single computer and a single software package can manage all data acquisition, even when dealing with many seismic sources firing at the same time.

The possibility to visualize and view different aspects of an area, e.g., as a side scan sonar mosaic, a bathymetric chart and a map with thickness of shallow and deep strata, including the basement depth, is truly of value for anyone making decisions on the future of a project.

When firing many seismic sources on board the only additional care to take is about the setup geometry, e.g. the distance between the seismic sources in, and around the boat, in order to avoid cross talk interferences.

If the system is run in near shore areas, it is very easy to set everything inside the boat. Figure 1 shows a complete system installed in boat in Santos area. In this case a complete system means: a single beam echo sounder (dual frequency: 38 & 200kHz), a side scan sonar (dual frequency: 100 & 500kHz), a dual chirp profiling system (2-8kHz & 10-18kHz) and a boomer (500-2000Hz).

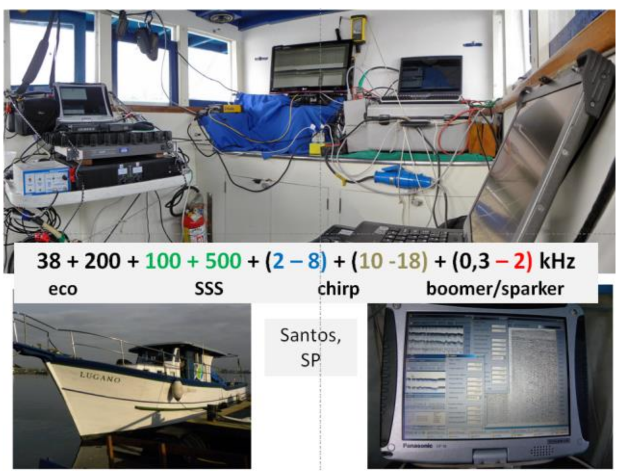

Figure 1: The system applied for survey a navigation channel in Santos, São Paulo. The above photo shows the interior of the boat with all systems installed; the lower left photo shows the boat used for this survey; the lower right photo shows the screen of the software with all seismic profiles running (IPT, 2011b).

When working in shallow lakes the size of the boat can be limited and in these cases it may not be possible to have everything running in the same boat at the same time. On such restricted environments one can still consider using as many different seismic sources as possible, but only one or two at a time. The example you see on Figure 2, it was decided to first survey using a bathymetric and side scan sonar system, followed by a chirp and boomer survey. That means, the same profiles were acquired twice but with different systems.

Figure 2: A small boat with a boomer and a double chirp at Ibirapuera lake, São Paulo city. IPT, 2011a.

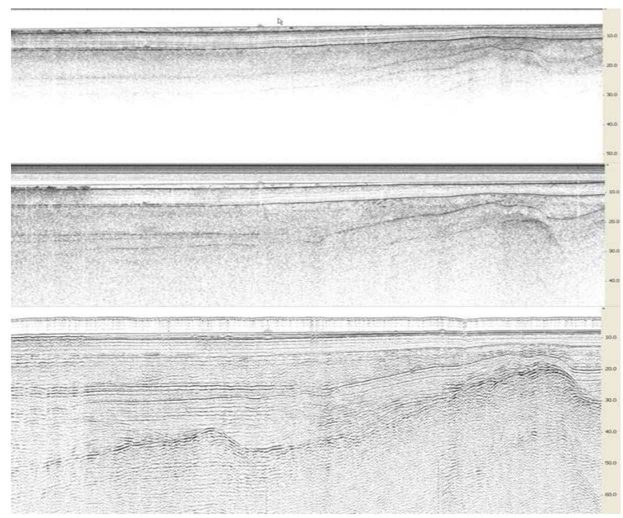

Figure 3: Examples of profiles obtained with three different seismic sources. The first one using a high frequency band from 10 to 18kHz is a chirp profile and shows high resolution data and poor penetration; the second one, using intermediate range of frequency (2-8kHz) is also a chirp and while still showing good resolution shows also a better penetration; the last one, using a very low range of frequencies (300-2000Hz) is a profile from a boomer. This profile shows how deep a boomer can go, as we see clearly the basement rock but lose on the resolution. Vertical scale in meters. Data from Gulf of Finland. Courtesy of Meridata, Finland Ltd.

Conclusions

Based on examples presented in this article we can make conclusions on the importance of multi-frequency approach for shallow water investigation projects.

If a project only needs information about the bottom surface, one could approach it using only a bathymetric (single or multibeam) system, possibly supplemented by a side scan sonar system. Data from these systems allow one to build a very useful 3D map, accompanied by a very comprehensive mosaic with side scan sonar images.

However, if a project requires information about subsurface strata, sub-bottom profiling systems will be needed too. When we start to talk about sub-bottom profiling systems we should have in mind two possible tracks for the discussions. The first one goes towards the resolution as a main target. In this case, high resolution systems like, chirps, SBP or parametric systems or even some low frequency bathymetric systems, will give the best solution. Sediment strata to a few centimeters in thickness can be resolved when using this type of systems.

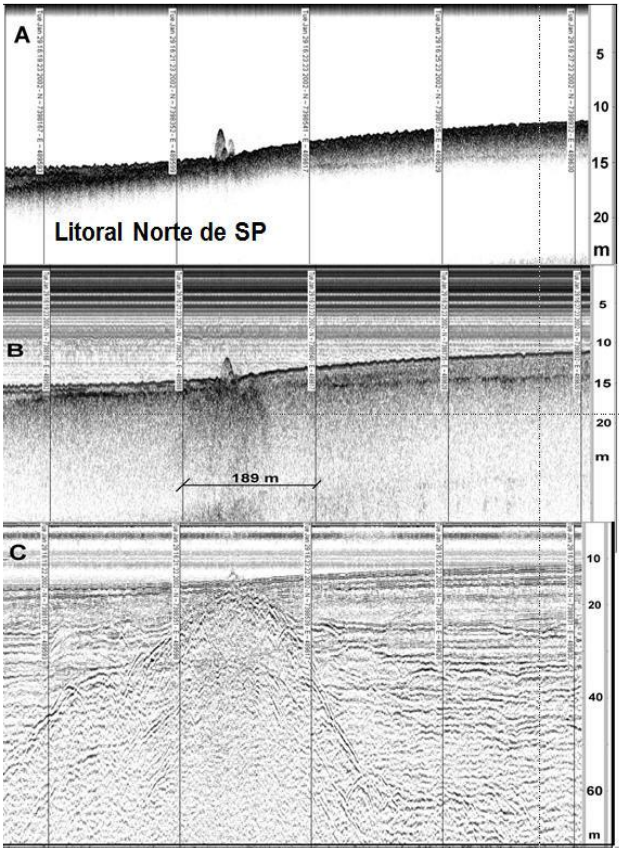

Figure 4: three seismic sources operating simultaneously with distinct differences in resolution and penetration performance. A) pinger 24kHz B) chirp 2-8kHz C) boomer (400-2000Hz). Courtesy of Dr. Michel M. de Mahiques – IO-USP.

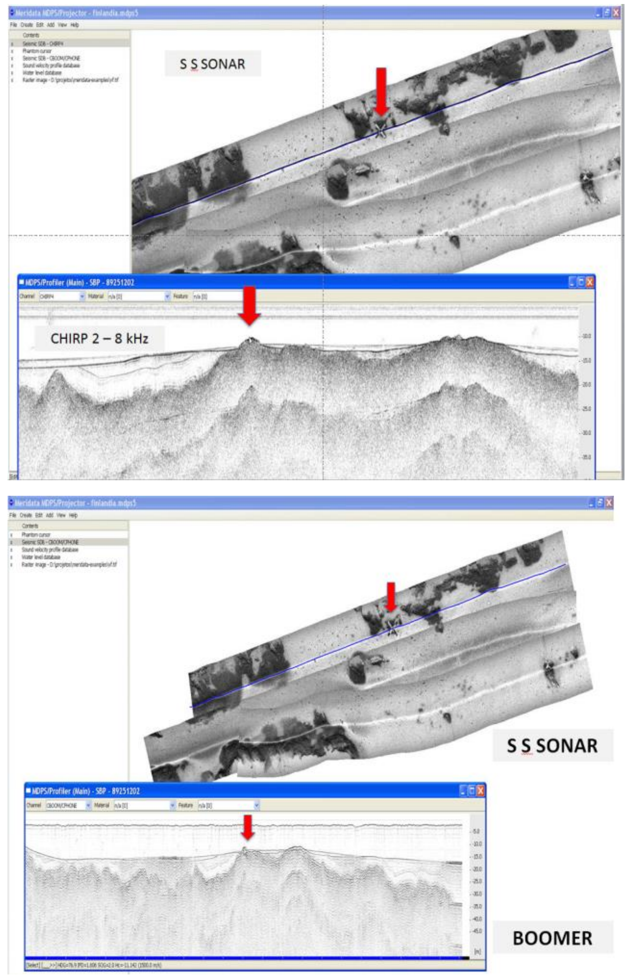

Figure 5: Side scan sonar mosaic and chirp 10-20kHz, chirp 2-8kHz and boomer profiling systems working together in the Gulf of Finland. These images show the expanded benefit of running a sub-bottom profiling system simultaneously with side scan sonar. Courtesy of Meridata Finland Ltd.

When the targets are thick layers located dozens of meters below the bottom surface, powerful seismic sources should be used. Here we are talking about boomers, sparkers or even low frequency / high energy chirps. Dealing with frequency range from 300-500Hz to 2000-4000Hz this type of profiler can go as deep as 100 meters, or in some cases, more than a hundred meters. The only care we should take here is that as we go down in frequency, we lose in resolution. Stratum just few centimeters thick will be not detected using a boomer or sparker.

In fact, most of the projects nowadays need information in terms of resolution and penetration.

Knowledge about thin strata of sediments and also about the depth of basement rock is a common requirement in almost all projects under development lately.

Basically, we usually need to know about the thickness of very shallow strata just to calculate how much material we need to dredge or remove, to make a channel navigable again, for example. In the same project we might also need to know about the depth of the basement rock in order to guarantee safe foundations for bridges, tunnels, dams and so on.

The best solution to meet these requirements is to use multi-frequency systems. Figure 6 shows an example of full range seismic survey accomplished at Santos harbor area using an single beam double frequency eco-sounder (38+200kHZ), a double frequency side scan sonar (100+500kHz), a high frequency chirp (10-18kHz), a low frequency chirp (2-8kHz) and a boomer as a high energy/low frequency seismic source, all tools running simultaneously.

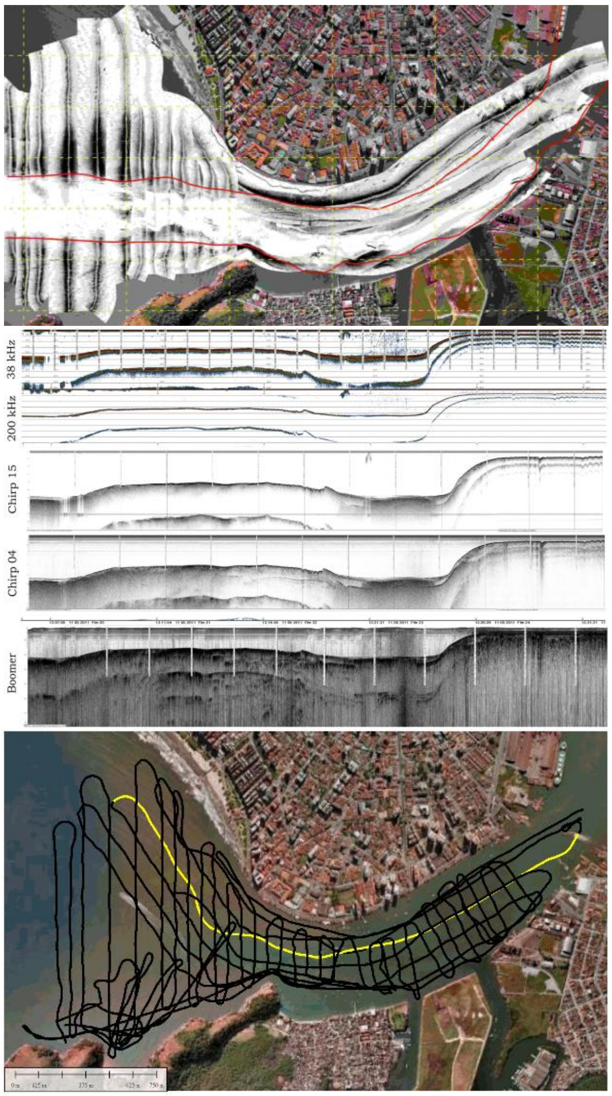

Figure 6: An example of multi-frequency approach on seismic survey in Santos harbor area. At the top, side scan sonar mosaic; at the middle, profiles from an eco-sounder (38 + 200kHz), a chirp (2-8kHz, a chirp (10-20kHz) and from a boomer (400-2000Hz). The map at the bottom shows the position of the profile (in yellow). IPT, 2011b.

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