Fundamentals of High Resolution Seismic Surveying

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High Resolution Marine Seismic Surveying

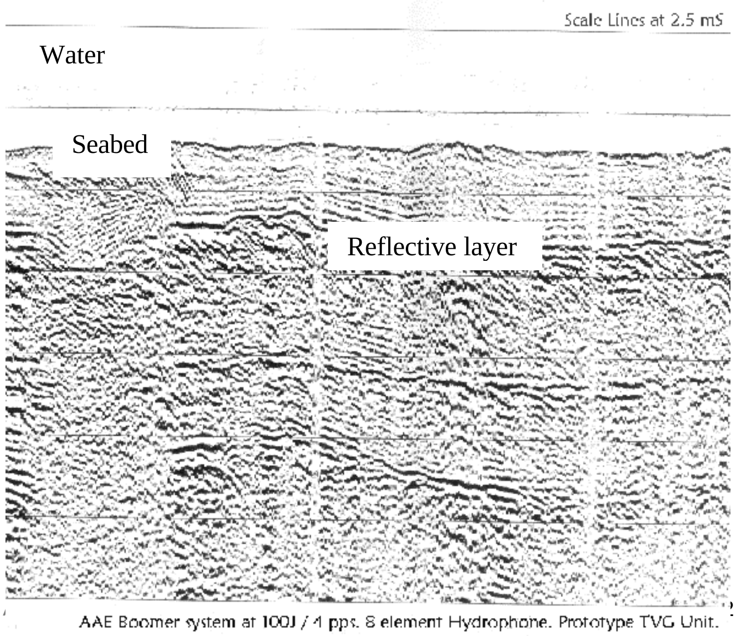
One of the most useful techniques in off-shore work is the application of seismic devices for sea floor engineering surveys. Although other manufacturers produce such equipment, Applied Acoustic Engineering have a dominant position as a supplier of boomer and sparker systems for use offshore, and the following text describes the use of the products available from our factory or our global network of agents.

General Description of Seismic Methods

The two basic seismic exploration techniques used at sea are seismic refraction and seismic reflection methods. The main difference between the two techniques is that in refraction work, the energy arrives at the receiver after travelling through the rock layers; whereas in reflection work, the energy is received after it has reflected from the subsurface layers. The following text describes the Applied Acoustic Engineering Boomer system as a reflection system.

Reflection Methods

The Applied Acoustic Engineering Boomer system as described consists of a towed sound source (often a Boomer Plate) which transmits sound energy in the form of a short pulse towards the seabed. This sound energy is reflected from the seabed and the subsequent layers of soil. The reflected energy intensity depends on the different densities of the seabed, the denser (harder) the seabed, the stronger the reflected signal. The reflected signal travels back through the water to a surface towed hydrophone (an underwater



AAE Boomer system at 100J / 4 pps. 8 element Hydrophone. Prototype TVG Unit.

microphone). The received signals are amplified, and returned to the vessel where they are processed and displayed.

The sequence is described thus:-

A transmission pulse from the boomer travels through the water at the same time as a recording sequence is started. As the signals travel in time to the seabed and subsequent layers of soil and returns, the synchronised record displays a line of signal on a paper recorder. The line contains signals proportional in intensity (darkness) to the strength of the reflected data. Another transmission pulse starts the sequence again to produce another line on the record. This sequence continues several times per second as the equipment is towed over the seabed, resulting in a record similar to the figure above of a cross section through the seabed.

Seismic reflection devices and techniques vary widely, but all have similar basic components. The four basic components in any seismic reflection system are:

1. A sound source that emits acoustic impulses or pressure waves. (The AA200 Boomer Plate, mounted on its catamaran, or our Squid Sparker).
2. An energy source to store energy for the sound source. (The CSP unit)
3. A hydrophone receiver that converts the reflected acoustic signals to electrical signals. (Streamer Hydrophones)
4. A display that makes a permanent record of the reflected signals. (Comprising of the shallow seismic processor and a graphic recorder).

Other electronic devices that are often used include analogue and digital tape storage, PC based display and signal processing equipment etc. although they will not be covered in this article.

The function and nature of the four basic components will be considered separately.

<u>Sound Sources</u>:

In the past for example, the detonation of dynamite charges tossed overboard from the vessel was common. In general, the hazards of using high explosives at sea make this technique somewhat undesirable! Commonly, boomer plates and sparkers are used. The boomer plate produces a sharp (short duration) broad spectrum pulse which gives a good trade-off of penetration vs. resolution. The frequency of the signal is between 500Hz and 10 kHz. A sparker (such as our *Squid 500)* provides a lower frequency pulse enabling greater penetration to be achieved but at the expense of reduced resolution. Both of the above receive energy from our CSP energy source.

Energy Source.

The energy source required to drive a boomer or sparker must be able to convert regular mains voltage into the high voltage necessary to energise the sound source. It must be able to do this safely and reliably, and be sited in a convenient location. It is also necessary to avoid the generation of electrical interference which characterised older designs which do not have a 'CE' mark and conform to the latest EU specifications for electro-magnetic compatibility. The CSP unit has the ability to store the amount of energy required for the high intensity sound pulses which are given by the Boomer or Sparker. The CSP is in turn connected to the boomer plate by a high voltage cable capable of safely carrying the high current (1500 amperes) high voltage (3500 volt) pulse with minimal losses.

Hydrophones:-

Hydrophones are usually towed away from the vessel, as ship noise is reduced by separating the active elements in the array from the ship through the use of a long tow cable. Selectivity is accomplished through having the array directional. The hydrophones in the array are spaced such that the signals arriving along the axis are phase shifted along the length (due to the time lag between the arrivals at each element). Because the phase shifting takes place along the axis, the summation of the phase shifted noise from the ship is less than the summation of the coherent signals arriving from the bottom.

Another significant source of noise, tow noise, is minimised by the mechanical design of the array (the streamlining, and the addition of a tail) again the summation of the signals on each hydrophone helps reduce noise.

The ambient noise, the noise from the wave action and the other sea noises which are present at all times, is reduced from the directional character of the hydrphone array. Since the ambient noise is essentially omnidirectional, the array is less sensitive to ambient noise signals than to the seismic signals which arrive normal to the array. The phase shifting further improves the signal to noise ratio relative to the ambient noise.

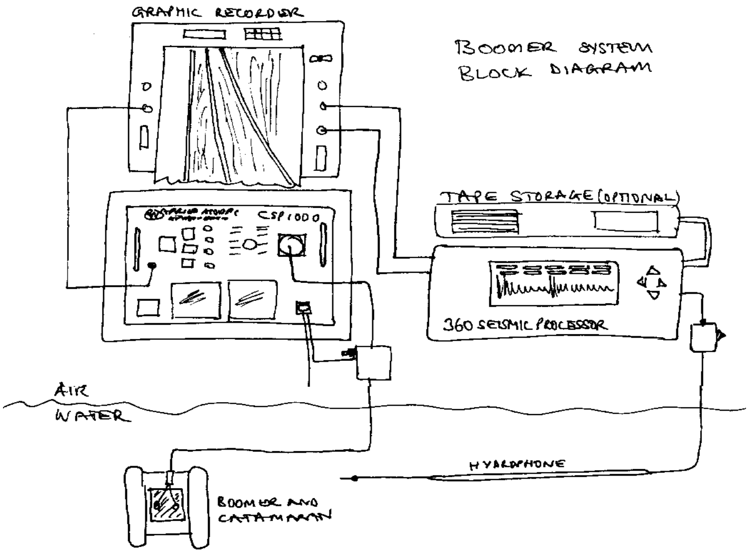
Streamer hydrophone towed from a boom.

The towed array receives a seismic signal which is composed of two distinct parts, a direct seismic signal which is echoed from the bottom and an indirect signal which is reflected from the surface. For maximum signal strength, these two arrivals should be in phase. This in-phase arrival usually occurs when the array is towed at a depth equal to a ¼ wavelength of the signal.

In deep water operations, the signals received at the array arrive from distances which are large, compared to the length of the array. In such cases, the signals arrive in phase and at times which are essentially the same. However, when the array is used in shallow water, the path lengths from the source to the bottom and to the separate hydrophones may be such that the arrivals are at different times and out of phase. In such cases the records would be smeared or distorted. In all cases, the Applied Acoustic Engineering hydrophones have been designed for durability and optimum performance with any sub-bottom profiler equipment.

Recorder & data presentation

The recorder is the visual interface for any seismic reflection system. In addition to tracing a profile of subsurface reflective horizons, the recorder also includes a control panel which allows the operator to select optimum repetition rate of the energy sources at various recording sweep rates. Gain controls are used to vary the intensity of the traced record. By programming appropriate triggering and gating sequences, most of the undesirable background noise generated by the instruments and by the ship may be eliminated.

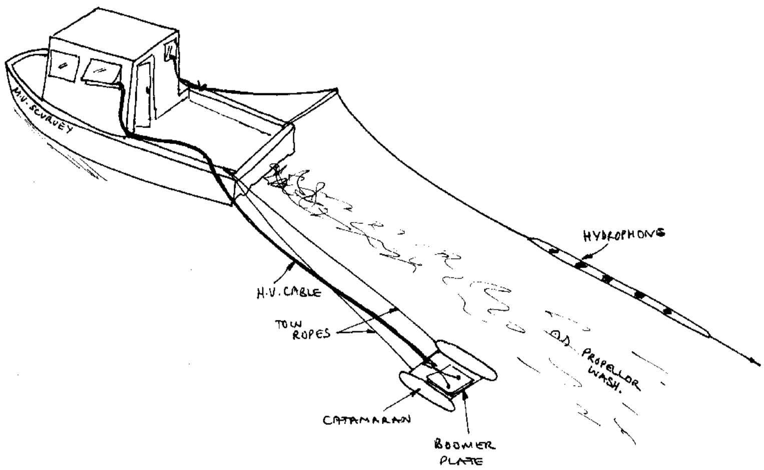


The scale of the printed record may be adjusted so that only pertinent data appear on the paper. A further refinement permits variation in the “sweep” rate (printing speed) of the print heads that traces the permanent record. An increase in the sweep rate narrows the range of observation on the record and correspondingly increases the vertical exaggeration inherent in all recording systems. Sweep rate is to some extent a misnomer nowadays, as thermal and other recorders no longer ‘sweep’ mechanically.

By using the advanced features of the digital 360 shallow seismic processor, such as band pass filtering, time varied gain (TVG) and other technology, the operator can obtain the best performance for a given seismic reflection system. There is also the facility for digital tape storage devices that records the raw signal as it enters the seismic processor. (Analogue tape recorders can also be used). This permits the replaying of the returning signals which, when coupled to the recorder in the laboratory, may result in a new record of a quality exceeding that of the initial record obtained aboard ship.

Applications

High resolution seismic surveys are primarily confined in the uppermost 60 metres of soil. This is the area where most engineering applications take place. It is estimated that about 80% of this work is done in the first 15 to 20 metres. Typical applications include reconnaissance geological surveys, mineral exploration, foundation studies for offshore platforms, and harbour development. Generally Boomer systems offer an excellent compromise between resolution and penetration. If greater penetration is required, a new generation of high quality sparkers (the Squid 500 for example) offer excellent performance, although for very deep penetration, other devices are required. If very high resolution sub bottom profiling is required, chirp systems can be very effective, but penetration is not as good as a boomer system.



Typical resolutions are as follows:-

AA200 Boomer Plate at 200J : 10cm
Squid 500 Sparker at 200 & 500J : 14 / 36 cm

Limitations

The quality of records obtained in seismic reflection studies depends greatly on the presence of subsurface horizons which will reflect acoustic energy. Differences in soil type, density, water content, and degree of solidification greatly influence the reflecting properties of buried layers.

There are a number of other factors that bear upon the success of a seismic reflection survey. These may be conveniently grouped into three classes; external, vessel and instrument limitations.

External Limitations are those that cannot be controlled. The major external factor is weather: rough seas not only create discomfort and difficult conditions aboard ship, but cause an increase in background and aeration noises created by breaking waves. This may reduce the quality of the records.

Another problem is that of ice. It is not common in most marine surveys, but it can hamper or cancel operations on inland waters.

Vessel limitations can be generally overcome by evaluating the survey requirements and by thoroughly checking the vessel's capabilities before the survey. In some cases, there may be electrical or mechanical interference between the ship's equipment and the seismic instruments.

Instrument limitations vary with individual systems, but in general the following factors are inherent in all seismic reflection devices:

1. The seismic records show layer thickness as a function of time, thus the true thickness may only be determined if the speed of sound through the material is known. Accurate sound wave velocity data are seldom available, therefore layer thicknesses must be considered approximate.

2. The reflecting surface does not always represent a change in the sediment type, but may only be a change in the physical character of the soil such as grain size, porosity, density, or hardness. Therefore, care should be exercised in evaluating the strength (darkness) of the recorded signal.

3. At greater water depths, the area of sea floor receiving sound increases. Thus, records in deep water will tend to show average conditions over an area rather than a specific profile directly below the ship.

Thus a number of precautions must be taken when the records are interpreted.

SEISMIC RECORD INTERPRETATION

The following is just a brief guide.

Because the transducer is a three-dimensional sound source, some care must be given to the interpretation of seismic profiling records obtained with conventional two-dimensional graphic recorders. Several factors can cause spurious tracks to be introduced into the records, and judicious analysis is often required to separate the spurious signals from true bottom and subbottom reflections. This is particularly true in those instances where the bottom or subbottom traversed has considerable deformation or anomalies.

In general, there are five different types of spurious signals that may cause confusion in the strip-chart records.

There are:

1. Direct Arrival- the signal received directly from the sound source.

2. Reflection Multiple- the repeated echo of a reflection from the bottom or subbottom.

3. Water Surface Reflection.

4. Side Echoes- side reflections from irregular bottom or subbottom features.

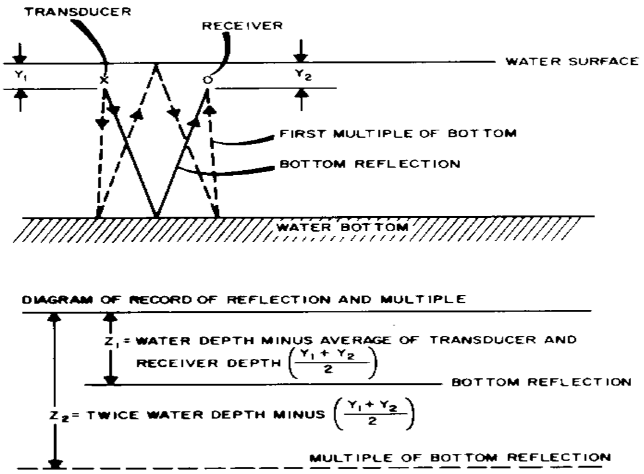
5. Point Source Reflections- reflections from single point objects that radiate reflected energy.

<u>Direct Arrival</u>-If the distance from the sound source to the receiver hydrophone or pickup is less than twice the distance from the receiver hydrophone to the bottom, the first signal recorded after zero time line, will be the direct signal from the sound source to the receiver. Since it will be the strongest signal recorded, it may be accompanied by some filter ringing that will make the event appear as a series of parallel lines. The direct arrival signal can be distinguished from the reflection signal of the bottom by the following characteristics.

1. The direct arrival signal will be displaced from the zero line at a distance that corresponds to the hydrophone-to-sound source distance, as scaled from the record.

2. The direct arrival signal trace will remain essentially parallel to the zero line, whereas the true bottom reflection line will often show some slope or irregular features. (If the receiver hydrophone wanders in the water, this could cause additional confusion.)

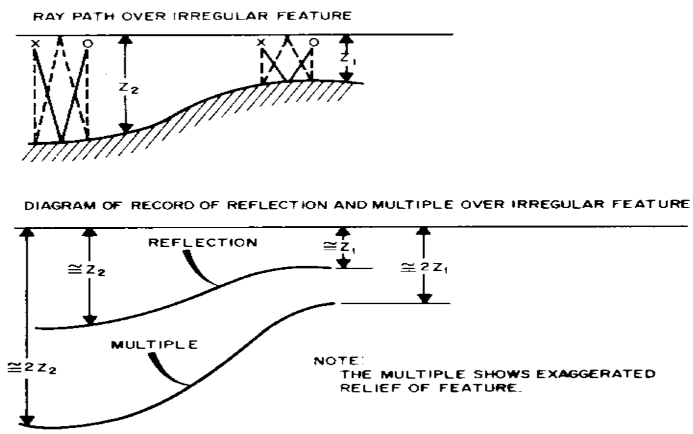
If it is difficult to differentiate between the direct arrival signal and the true bottom reflection signal, or if the direct arrival signal occurs at the time that causes masking of the bottom reflection, changing the hydrophone to transducer distance should correct the situation.



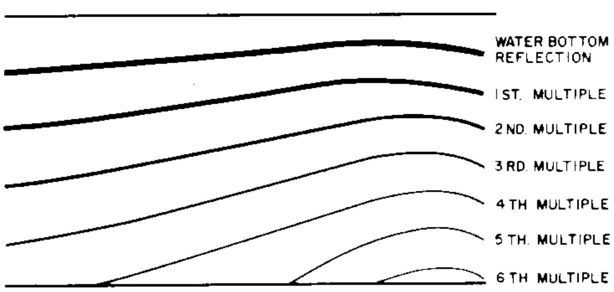
Reflection Multiples- In areas where very strong bottom reflection signals are encountered, echoes of the strong bottom reflection signal may mask signals from subbottom reflections. Reflection multiples may be distinguished from subbottom reflections by the following characteristics.

1. The bottom reflection multiple will be spaced from the true bottom reflection at a scale distance that corresponds to the depth of water.

2. Irregular bottom features shown in the true bottom reflection will appear in exaggerated relief at the same point in the reflection multiple, as illustrated below:-

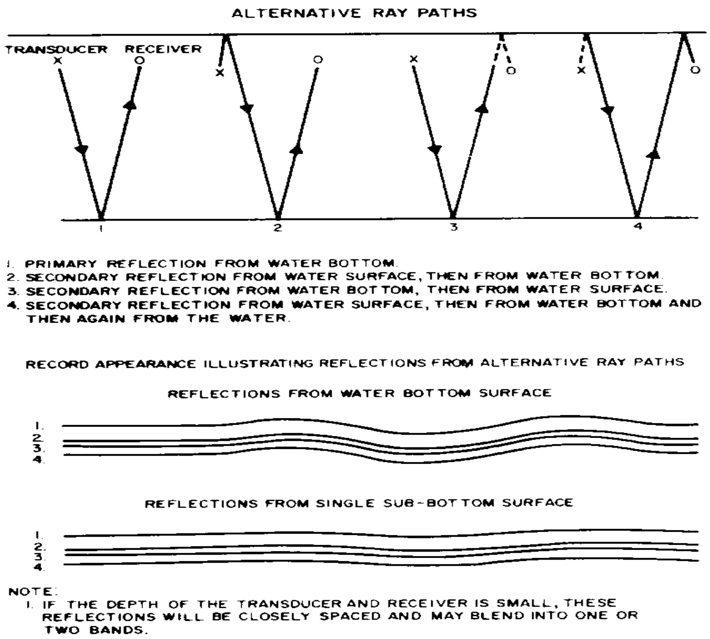


3. Frequently, more than one multiple will be recorded, and a series of regularly spaced, consecutively lighter traces will appear in the record (with irregular bottom features assuming more exaggerated appearance in consecutive traces).



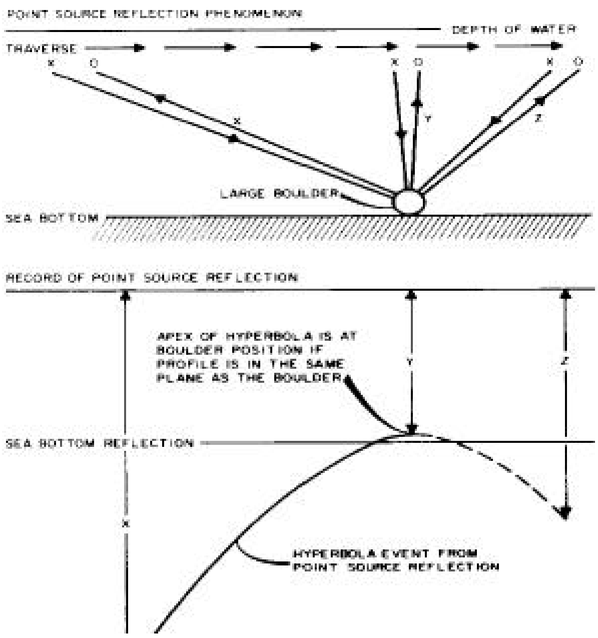
WATER SURFACE REFLECTIONS-Because the sound source acts as a point source, radiating energy in all directions, a portion of the pulse energy will travel upward from the sound source to the water surface and be reflected down to the hydrophone.

This water surface reflection signal will result in a trace essentially parallel to the zero line (allowing for drift of the hydrophone and sound source) at a distance that is scalable to the sound source to surface to hydrophone distance. This signal and any of its multiples can be identified by experimenting with different hydrophone and sound source depth distances.



SIDE ECHOES- In areas where there are sea-bottom irregularities or considerable structural deformation, side effects may cause confusion. A side echo from a sea-bottom feature will have only two or three cycles that will cut across the subbottom reflections at an angle. This helps to distinguish the side echo from subbottom reflections. Subbottom reflections generally will be more or less uniform because subbottom sedimentary layers usually have flatter, more uniform bedding features. In complex structural areas, offsetting of reflections and three-dimensional model analysis may be necessary for a complete interpretation. However, such analysis is beyond the scope of this paper.

POINT SOURCE REFLECTIONS-The signals received from point source reflections are actually side-echo reflections from distinct point objects in the area where the traverse is being run. These point source objects usually produce hyperbola-shaped signals that are sharpest when the point object is in a direct line with the traverse. Objects off to one side will record lower in the record and be of a broader pattern, a pattern similar to that of a buried or subbottom point source anomaly. Repeated traverses in an area will usually serve to identify



whether a point object is below or off to one side.

Usually seismic strip-chart records can be readily interpreted and used to identify bottom and subbottom profile information in light of known geological information. In most marine engineering applications, coring information is required for comparison between geological horizons or sedimentary layers to seismic records.