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A Review of Various Technologies for Depth Measurement in Estimating Reservoir Sedimentation

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Abstract

Estimation of silt based on under water depth measurement is of high importance in the hydrographic survey activity especially in reservoirs. Many technologies and techniques have been proposed from last 50 years for depth measurement. All of them have their own advantages and disadvantages. In this paper we have revived the existing depth measurement techniques focusing on its usage, advantages and disadvantages.

The measurement technique successfully used in reservoirs is single beam depth sounding. But other techniques are evolving which provide much better results at higher acquisition rate than single beam eco-sounder. These include multiple beam eco systems, airborne laser systems and airborne electromagnetic systems among many others. However the higher techniques other than single beam are not often applied in sedimentation calculations in reservoirs.

1. Introduction

For hydrographic survey depth measurement is the fundamental task. Hence the hydrographer needs to have specific knowledge of the medium and the underwater acoustics along with the devices available for depth measurement and the proper techniques used for accurate depth measurement.

Single beam acoustic depth sounding is far the ubiquitous solution. First used by Corps back in 1920s, it did not replace the reliance of lead line depth measurement until mid-1900s. A variety of acoustic depth systems are depending on project conditions and depths. These include single beam transducer systems, multiple transducer channel sweep systems, and multibeam sweep systems.

Although manually operated sounding lines and poles may be considered as outdated, but they are still viable means of depth measurement in reservoirs with thick vegetation and shallow depths. They can also be used to confirm the readings form other techniques in cases of questionable readings. Such faulty readings are common near vertical walls or from silty bottoms containing fluff or light suspended material. These conditions can very well be confirmed by manual collection methods and can also determine the type of material on reservoir.

During the last decade, hydrographic surveying has experienced a conceptual change in depth measurement technology and methodology. Multibeam echo sounders (MBES) and airborne laser sounding systems (ALS) now provide almost total bed coverage and depth measurement.

Although multibeam systems are increasingly being used for surveys of deep-draft projects, single beam systems are still used by many. But these echo sounders have now evolved from analogue to digital recording, and also with greater precision and better accuracy.

When full bed ensonification is required, multibeam and airborne systems are used. Airborne laser sounding have by far the highest data acquisition rate but their high initial cost is an important factor.

2. Single beam eco sounding

This system employs transmission of ultrasonic beam towards the bottom and then by measuring the time interval required for the beam to reflect and travel back to the transducer, the depth is determined. It produces consistent high resolution vertical bed profile.

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2.1. Principle

An electric pulse is sent to the transducer. The transducer then sends an ultrasonic waver for a short period of time. The pulse is emitted in the downward direction form the emitter which is usually mounted beneath a boat. After reflection, the echo is captured and the time interval is recorded, previously on a CRT and now thanks to modern technology it is stored directly on a computer. Ultrasonic depth measurements have a service range up to 10 km, depending on the working frequency.

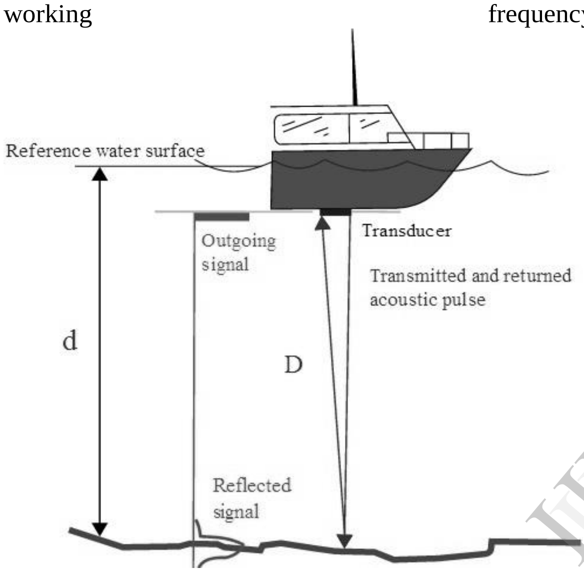

Fig.1. Single beam eco sounding

The depth can be expressed by the following general formula: $d = ½ (v • t) + k + d_r$
Where:
d = corrected depth from reference water surface
v = average velocity of sound in the water column
t = measured elapsed time from transducer to bottom and back to transducer
k = system index constant
d_r = distance from reference water surface to transducer (draft)

The parameters v, t, and d_r cannot be perfectly determined during the echo sounding process, and k must be determined from periodic calibration of the equipment. The elapsed time, t, is dependent on the reflectivity of the bottom and related signal processing methods used to discern a valid return. The shape, or sharpness, of the returning pulse plays a major role in the accuracy and detection capabilities of depth measurement.

2.2. Velocity

The velocity of sound, v, is perhaps the most difficult parameter to determine. It varies with the density, elastic properties of water which in turn varies with the temperature and suspended or dissolved contents. Since the temperature doesn't remain constant with depth, the average value is taken. It ranges from 4,600 to 5,000 ft/sec.

The velocity of ultrasound waves increases with the temperature till around 74 degrees and then decreases. This can be expressed as:
$v = v_{max} - 0.0245(t_{max} - t)^2$
Where:
v_{max} = the maximum velocity of ultrasound in water
t_{max} = temperature of water at maximum velocity
t = current temperature of water

2.3. Frequency

Usually two channels are used for low and high frequency. This helps in separation of signal return from soft surface sediments and underlying rock due to difference in their acoustic properties.

The desired frequency used is highly site dependent. It varies with the depth. In cases where one device is intended to be used for varying depth, varying frequency is used. This frequency is allotted to the channels. Lower frequency transducer tends to have longer beam widths, thus can cause distortion but less attenuation allowing greater depth measurement. High frequency transducers will provide more precise depth measurement and narrow beam widths with more attenuation. For typical reservoirs a frequency around 200 kHz is used which is ideal for water shallower than 100 meters. Change in frequency will change the depth of penetration as well as the medium of penetration. Using this property depth is measured for normal water as well as the soft silt below water. All the collected data points are integrated with proper mathematical equations to estimate volume of different layers, by which the silt volume is estimated.

2.4. Capability and limitations

While simple and inexpensive method, single beam eco- sounders have a number of critical limitations that make it an inappropriate instrument for large scale bathymetric survey work. It doesn't produce accurate depth measurements that correspond to well defined locations on the bottom bed and it doesn't make large numbers of these measurements in a reasonable amount of time, thus limiting the acquisition rate.

3. Multibeam eco sounding

Multibeam technology was originally developed in the 1960s for deep water mapping and was then further extended to shallow water applications. Multibeam echo sounders have then become more popular over the last few years. It is simple to operate and provides better resolution and increased floor coverage.

3.1. Principle

Multibeam systems are fan-beam acoustic systems consisting of a number of narrow single beam transducers mounted in close proximity and focused at equally spaced angles form a location under the survey boat. After the reflection of the acoustic energy by the seabed, the two way travel time is computed. Then the depth is determined, along with the transversal distance to the centre of the ensonified area.
Since the measurement the measurement of range and beam angle for multibeam is more complex as compared to simple single beam eco sounders, a number of factors contribute to the error in the readings.

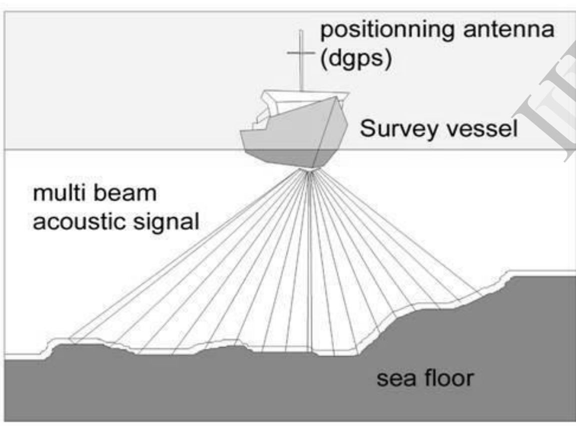

Fig.2. Multibeam eco sounding

3.2. Installation

Installation of the transducer depends on the system portability, noise and various other factors. The transducer can be keel mounted, towed or portable. Transducers are keel mounted in case of large vessels. Towed mounted transducers are used for side scan sonars when it is essential to have good stability of the transducer and reduction of vessel noise. Side scan sonar is a high-resolution tool that provides a map on both sides of a survey vessel's path. Portable is the most common installation method for reservoirs.

3.3. Frequency

Frequency of multibeam eco sounders are selected based on the intended use of the equipment, the typical frequencies being higher than 200 kHz for water shallower than 100 meters. For deeper water bodies frequencies from 50 to 200 kHz is used.

3.4. Capabilities and limitations

Multibeam systems with their capability of full seafloor ensonification contribute to a better seafloor representation and, when compared to SBES, to higher mapping resolution. However, as far as the depth measurements are concerned, resolution will depend on the acoustic frequency, transmit and receive beam widths and on the algorithm used to perform seabed detection.

It provide hydrographic data only along a single path directly beneath the track of a surveying ship. Sonar systems based on acoustic echo sounding methods require surface vessels to carry them and thus the speed of acquisition of bathymetric data is limited by the speed of the vessel. Moreover, hydrographic survey ships cannot operate safely in shallow waters.

4. Airborne laser systems

The Airborne laser systems are based on extensive field experiments and theoretical research and simulations. The first operational systems did not appear until the mid-1980s, the laser bathymetry concept was first conceived, and systems proposed in the 1960's. They offer both an alternative and a complement to survey with acoustic systems. These system composes of a laser scanning system, global positioning system and an inertial measurement unit.

3.2. Principle

LIDAR (Light Detection And Ranging), is a system for measuring the water depth. A series of short pulses of blue-green laser light along with infrared pulses are projected simultaneously form the aircraft into the reservoir. The surface and the bottom of the reservoir reflect the blue and green laser light whereas the infrared pulse is scattered by the water surface. The time delay between the surface and bottom reflections are then used to calculate the reservoir depth.

The depth calculation is according to Snell's law,

$$\sin \theta_a / c_a = \sin \theta_w / c_w$$

where θ_a and θ_w are the incidence angles in the air and into the water and c_a and c_w being the speed of light in the air and the water.
Temperature, pressure and salinity affect the propagation of light through the water. The transparency of water also plays a major role. The transparency in a function of the suspended particles in the water.

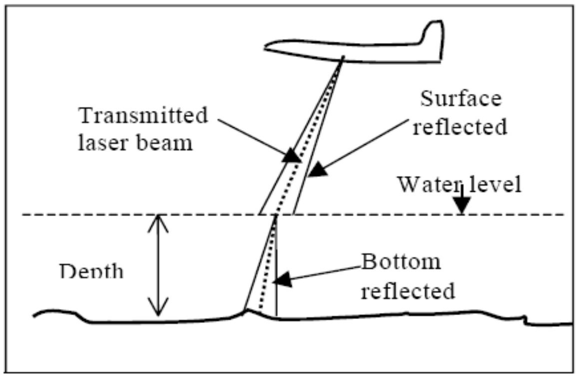

Fig. 3. Airborne laser systems

3.3. Capabilities and limitations

These systems have very efficient and have very high speed compared to the traditional acoustic systems. Also the speed is not dependent on the water depth as it is in acoustic systems. Laser systems give good coverage, close to full coverage, in extreme conditions of temperature, where acoustic systems may produce poor quality data. They also provide good coverage and can be used in places where it is not possible to take boats. Safety is also a major advantage of laser systems.

But water clarity is the primary constraint of LIDAR. LIDAR has been successful at collecting bottom data through as much as 40-meter depths of clear water. In less clear waters, LIDAR data collection has been successful at depths of two to three times the visible depth. It is very sensitive to suspended material and turbidity of water. One major factor is that the initial and operational cost of airborne systems are substantially higher.

4. Airborne electromagnetic systems

Airborne time-domain electromagnetic systems have been in development for over 50 years. And this system was further developed for mapping floor formations in shallow water.

4.1. Principle

The basic principle applied here is based on a geophysical survey technique for measuring the electrical conductivity of bedrock or the thickness of a conductive layer.

The basic setup of an EM surveying system includes a transmitter loop and a receiver coil placed on a helicopter or a fixed wing aircraft. The transmitter consists of a wire loop of one or more turns that carries the current generated by a power source. Circulating currents in the loop generate a primary induce. Diffusion processes induce eddy currents within any surface conductors. Eddy currents create a secondary field of their own. Primary and secondary fields are detected by the receiver coils. As a changing field passes through the receiver coils, an induced voltage is measured according to the Faraday's law of induction.

Assuming horizontal layers, signal processing in time or frequency domain can be used to determine the conductivity, σ_w, and thickness of the seawater column, i.e. the water depth, and conductivity, σ_s, of the seafloor.

4.2. Capabilities and limitations

These have some of the same advantages as that of air borne laser systems, viz. high speed of data acquisition as compared to the traditional acoustic systems and they also provide good coverage and can be used in areas, where it is not possible to take boats. Since they use low frequencies, they can also be used for operating over thick ice

The initial cost here is high as compared to the acoustic systems. Also, the system is at present, for reconnaissance purpose only. In the range of 0–40 m of water, the representative difference between the interpreted depths and the charted depths is about 2 m.

5. Photo-bathymetry

Aerial photography is commonly used to delineate the boundaries of reservoirs and, are many a times very useful in reconnaissance, planning of hydrographic surveys, and creation of a qualitative description of the floor rather than by mans by which to determine the water depth.

5.1. Principle

Aerial pictures are digitally processed to extract various information form the image. Digital image processors have the ability to correlate light intensity with depth. However, this is function of the material in suspension, clarity of water and also on the reflective properties of the bottom surface. Thus a local calibration should be undertaken to account these variations.

Fig.4. Depth analysis using Photo bathymetry

5.2. Capabilities and limitations

This method is very fast as compared to the earlier images. And with the ever increasing computational power of computers and other technological advances, the speed also goes on increasing while the cost goes on decreasing.

But the applications, within the present limits of this technology, remains mainly a tool for reconnaissance and planning in areas where there is insufficient or no depth information, as the exact depth cannot be measured with it.

6. Mechanic systems

Various factors such as water characteristics have direct as well as indirect impact on the systems discussed earlier. Mechanic systems are not sensitive to such environmental changes. These systems though very old, still remain in use even today.

6.1. Lead line and sounding pole:

Lead lines are ropes or lines with depth markings and lead weights attached at regular intervals. These lines are lowered and the line is used for determining the depth of water when sounding manually, generally, in depths of less than 50 meters.

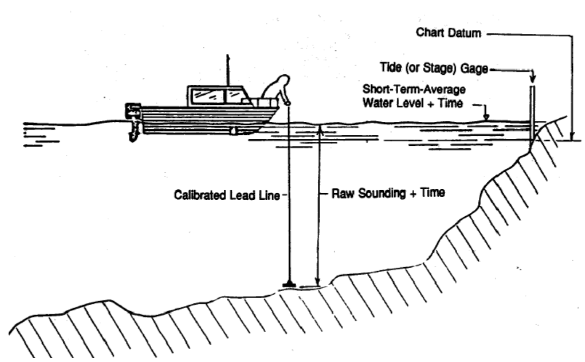

Fig. 5. Lead line

6.2. Capabilities and limitations

The lead line aids the hydrographer in resolving echo sounder misinterpretation caused by spurious returns. Lead lines and sounding poles are a labour-intensive and time-consuming process. While the initial depth soundings may have been accurate, they were limited in number, and thus, coverage between single soundings was lacking.

7. Conclusion

From 1960 to 1980, major technical advances took place in depth measurement techniques. These technologies continue to advance leading to more robust methods, simplifying the task of a hydrographer even today. Newer systems and methods under development are becoming more viable for survey applications. Thus, it can be concluded that depending on the requirements and applications, different techniques have different advantages and disadvantages, and it is the job of the hydrographer to decide which technology suits best for the given conditions.

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