EFFECTS OF INADEQUATE SURFACE SOUND SPEED MEASUREMENTS IN MULTIBEAM ECHOSOUNDER SYSTEMS

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ABSTRACT

In any type of survey work, variation of the characteristics of the medium through which the measurements are made is a challenge, thus; having serious effects on the accuracy of the measurements. In hydrographic surveying, the effects are even greater when using sonar techniques. The single most important acoustical variable in the water is its speed. Average speed of sound in the ocean is 1500m/s. But its precise value in a location is strongly depending on temperature, pressure and salinity of that particular location. These factors changes rapidly in time and space due to various reasons like solar heating, evaporation, precipitation, fresh water inflow etc… and water movements like tides, currents and wave actions. In data acquisition, the collection of these dense sound speed data becomes critical. These inadequate sound speeds create unknown propagation through the water column that adds a major uncertainty to multibeam echosounder (MBES) measurements. There are two types of sound speed measurements made in Multibeam sonars. Surface sound speed (SSS) measured at the face of the transducer and sound speed profile (SSP) through the water column. SSS is used to determine the beam pointing angle and SSP is used to determine the depth and position of each beam. This paper explains the necessity of the surface sound speed in multibeam sonars and effects generated by inadequate SSS measurements using real data from RESON SeaBat 8124 multibeam system. When the vessel roll is significant, the roll modulate the errors induced by erroneous SSS measurements. These errors are illustrated in relation to the IHO standards.

Keywords: *multibeam echosounder system, surface sound speed, beam steering*

1.0 Introduction

Since the advent of the echosounder, it has been a challenge of making sound speed measurements. The nature of the sea environment is dynamic and more complex. Its physical and chemical composition varies with time and space so rapidly. Water varies from cold to hot, fresh to saline and shallow to deep. Surveys undertaken in each cases and the behaviour of the sound wave is different in each. Average sound speed in the ocean in global perspective is about 1500 m/s. But its true value is strongly dependant on the temperature, pressure or depth and salinity of that particular point. Even more, water movements like waves, tides, currents, up-welling etc, mix altogether and make a complex sound speed structure (Figure 1). At the end, resulting unpredictable sound speeds.

Figure 1: Complexity of sound speed structure in the ocean (OMG-UNB).

Multibeam echosounder systems (MBES) are used to increase bottom coverage and consequently productivity in hydrographc surveys. Each of narrow beams produced in MBES yields a resolution of the bottom equivalent to that of a narrow single beam echosounder. The fundamental data received by these systems are two-way-travel-time of the short acoustic pulse from the transducer face to the sea floor and the direction of the reflection echo (Figure 2). However the final bathymetry is a result of processing information from several data sources like positional data from GPS unit, tidal data, vessel motion data, sound speed data etc. From these, sound speed measurements are the most critical (Gardner *et al.*, 2001) .

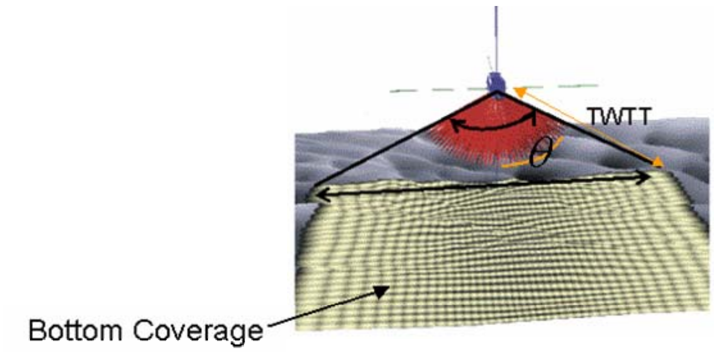


Figure 2: MBES coverage

2.0 Sound Speed Measurements in MBES

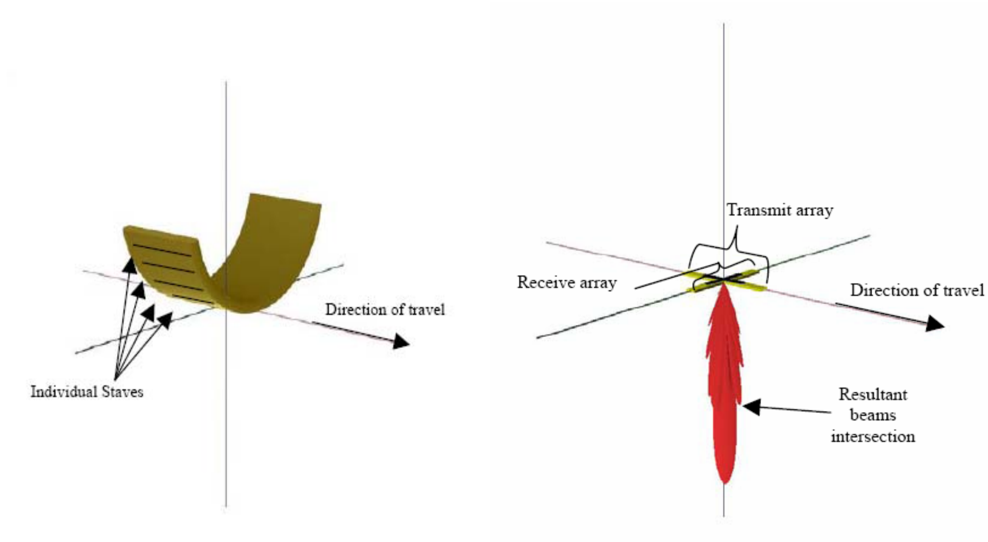
There are two types of sound speed measurements made in MBES, depending on the transducer configuration. Namely; the surface sound speed (SSS) and the sound speed profile (SSP). SSS is measured near the face of the transducer for the purpose of beam steering to determine the beam-pointing angle and SSP measured through the water column for the purpose of ray-tracing to determine the depth and the position of each beam. This study focuses on the technical aspects and the effects of inadequate SSS measurements in MBES.

3.0 Beam Steering in MBES

The concept of MBES is relies on beam steering. Beam steering is the process that enables a beam to be received from a desired angle, which are not orthogonal to the transducer array. Without steering, the narrow beams created by the product of transmit and receive beam patterns are always orthogonal to the array. In order to generate a fan of narrow beams in the across track direction, it is needed to direct this narrow beam in any of the directions from broadside with in the plane of ensonification. Unlike in single beam or multi transducer system, this way MBES achieve a wider coverage, maintaining the high resolution.

There has been different MB transducer configurations being designed so far. Each has its advantages and disadvantages. But mainly they can be divided into two groups, i.e. the curved array and the flat array (Figure 3). The curved transducers do not adopted beam steering. It uses its physical shape to achieve the coverage. But in flat array transducers, it is a must. They use electronic beam steering. There are three different types of electronic beam steering methods, namely time delay, phase delay and fast furrier transformation

(FFT). In each of these cases it need SSS at the face of the transducer to steer the beams.



(a) (b)

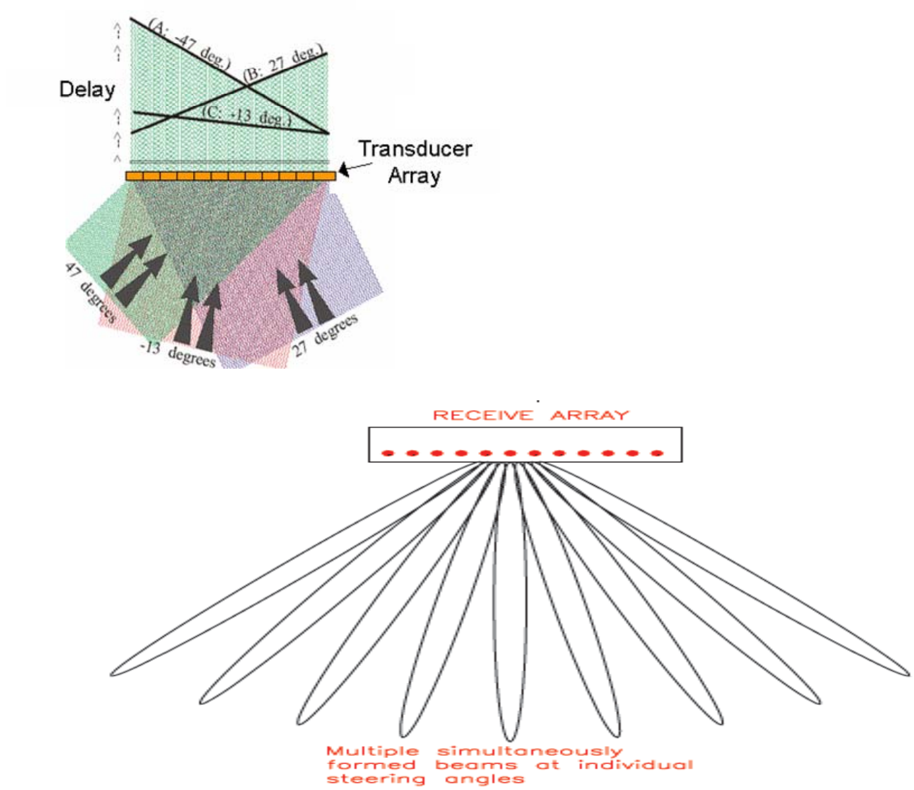
Figure 3: Different Transducer configurations. (a). Curved Array Transducer (b) Flat Array Transducer

3.1 Beam Steering in RESON SeaBat 8124

RESON SeaBat 8124 is a Mills T-cross type horizontal flat transducer array (Figure 4). The sensor array composed of a series of 72 elements, equally spaced (362mm), which generates 80 separate beams, creating a swath coverage of 120 degrees. The acoustic frequency of the transducer is 200MHz. (RESON Co, UK). It has a sound velocity probe mounted near the sonar head (Figure 4).

Figure 4: RESON SeaBat 8124 sonar with surface sound speed measurement probe

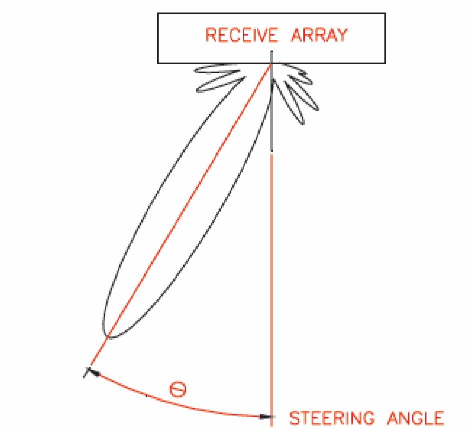
Figure 5 (a) explains schematically how beam steering is achieved in SeaBat 8124. The delays applied to each element in the transducer array in such a way that the oblique beams can be received. It is similar to physically rotate the transducer array to each direction. For example, without beam steering all the return echoes are parallel to the transducer array and to receive the 27 degree beam from the starboard side, it apply less delays to the elements at the ports side and more delays to the starboard side elements. Such technique creates a virtual array that is tilted 27 degrees to the starboard side. All other beams are also received accordingly in the same manner simultaneously. Figure 5 (b) illustrates how swath coverage is achieved in a flat array transducer and by this way; simultaneously transmits and receives all beams, which generate the swath coverage up to 3.5 times of water depth.



(a) (b)

Figure 5: (a) Applied delays to each beam to achieve desired steering direction.
(b) How all the beams are generated simultaneously by beam steering.

SeaBat 8124 uses the time delay method to steer the beams. Here the applied time delay between two transducer elements is a function of the wavelength (Burdic, 1991).



θ

Time delay at n^{th} element = $\dfrac{n \times d}{f \times \lambda} \sin\theta$

Where, θ = Angle to be steered
n = Element number
d = Element spacing
f = Frequency
λ = Wavelength

Figure 6: Steering Angle of a beam

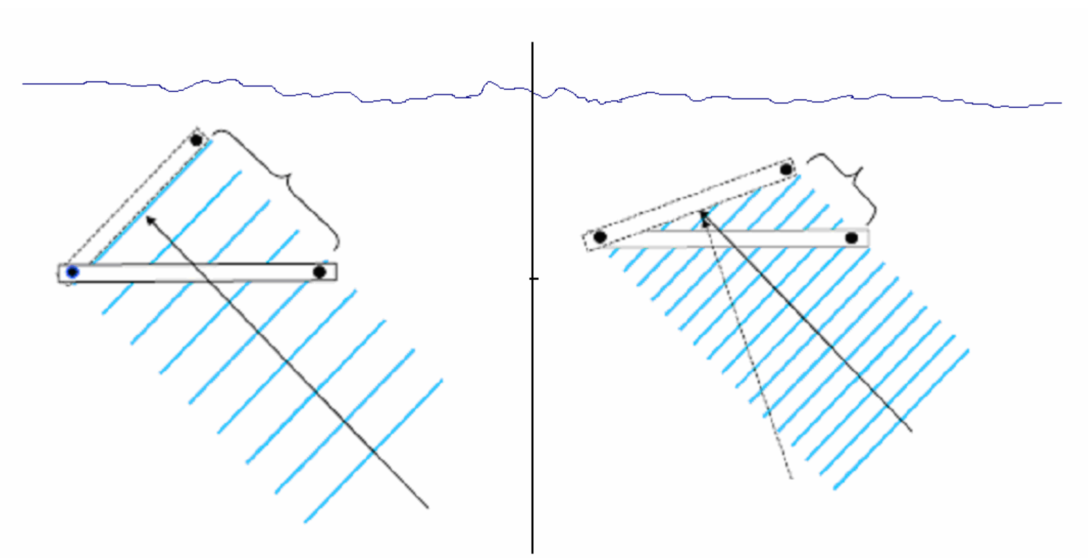
But, $\lambda = \dfrac{C}{f}$ Where C is speed of sound

True sound speed (C_0) near the sonar head with respect to the assumed or measured (C_1) at the face of the transducer causes the beams to deviate from the direction in which the transducer is supposed to steer (θ_0). It can be computed using Snell's law as follows.

$$\theta_1 = \sin^{-1}\{\frac{C_1}{C_0}\sin\theta_0\}$$

Here θ_1 is the actual angle of steering with respect to the measured SSS.

Figure 7 describes the error that occurs due to wrongly estimated SSS ($C_0 > C_1$). The estimated wavelength based on the measured SSS is shorter than the true wavelength. But the beam former still listens to (delay) the same number of waterfronts to steer the beam. It adds wrong delays to the elements and resulted in incorrect beam angle. Thus, the calculated departure angle is also incorrect.



(a) (b)

Figure 7: Effect of change in SSS in beam pointing angle in a flat array transducer:
In the case of true SSS is greater than the assumed or measured.
(a). Virtual array with true/known SSS. (b) Virtual array pointing towards wrong direction (incorrect SSS)

It is clear that the variation of SSS at the transducer face effects the steering direction of the beam.

3.2 Vessel Roll and Faulty Beam Steering

Roll is caused by the vessels rotation around y- axis of the vessels coordinates system. Roll effects the effective beam angle (angle with respect to the vertical/nadir). Thus, the effects can be illustrated using the following equation.

Effective beam angle (α)= Roll angle (ρ) + Beam steering angle (θ)

ρ θ

α

Figure 8: Effective beam angle due to vessel roll.

These effects are different for roll-stabilised and non-roll-stabilised transducers.

4. 0 Methodology

The effects are illustrated for an assumed synthetic flat sea floor of 100 m deep with different SSS speeds and roll angles. The depth and positional effects were evaluated.

In order to see the real effects, several survey lines were run at Lido Beach, Johor Bahru using RESON SeaBat 8124 MBES. Here same survey line was run with 'Real Time', 'Assumed' and 'No' SSS values. SSS in measured using the probe near the transducer and true SSP is applied for all the lines. The different SSS values were set to the system by switching off the SSS input and directly entering the desired values manually to the sonar processor (81P).

To study the SSS effects with different roll angles, survey lines having different SSS values, were replayed with different roll angles. Here, the desired roll values were added manually to the system.

5.0 Observations

During the field observation, we observed that SSS changes quite rapidly over the area. Even in the same survey line we had 3 to 5 m/s variations. The survey lines along the river mouth showed the most variations. And the covered area away from the river mouth gave the least SSS discontinuity.

5.1 Depth and positional effects

Figure 9 and Figure 10 shows the effects of the SSS in MBES for +ve and –ve sound speed variations in terms of depth and position. The higher the beam angle and the higher the SSS error, the depth and across track errors are higher with respect to the nadir beams.

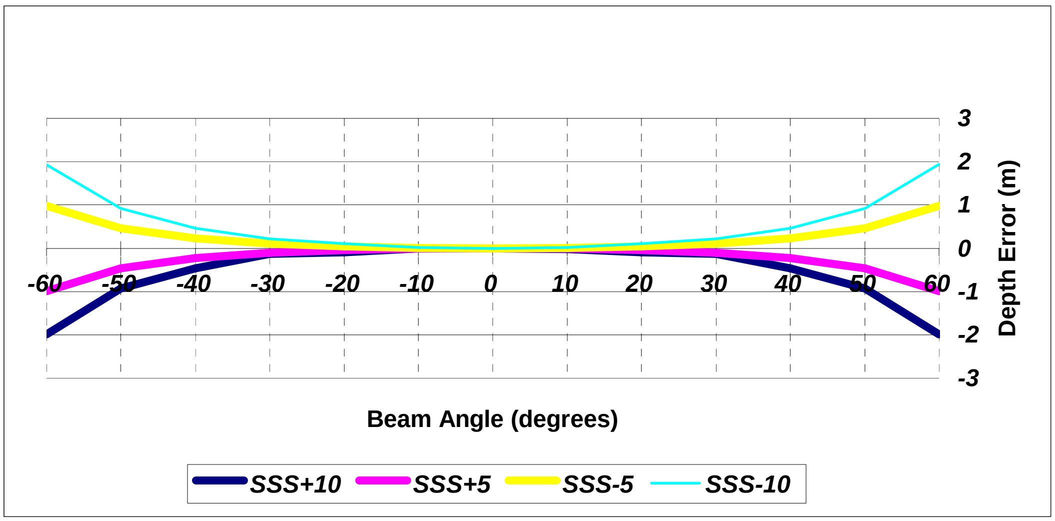


Figure 9: Depth error for 100 m sea bottom for different SSS errors.

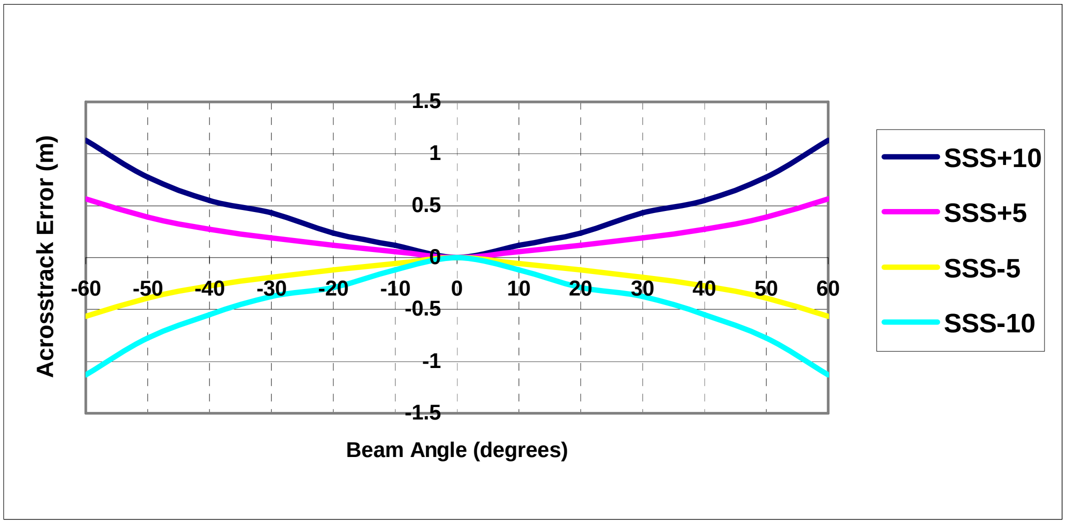


Figure 10: Across track difference for 100 m sea bottom for different SSS errors.

(a) (b)

Figure 11: Impact of surface sound speed errors on the shape of the swath of a flat transducer array for a flat sea floor. (a) For +ve SSS error it curl down (b) for –ve SSS error curl up. Note that the errors induced all over the swath except at the nadir beams.

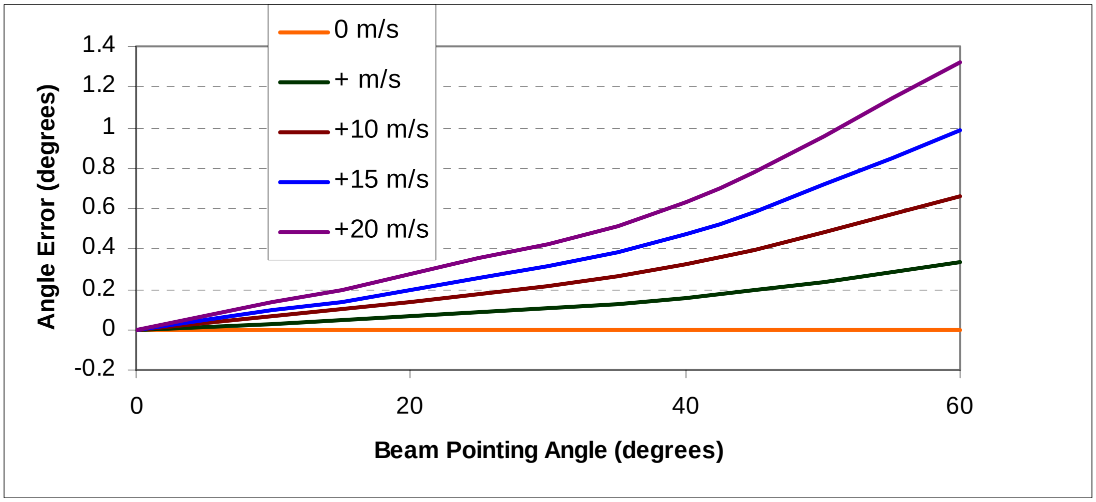


Figure 12: Angular error for different SSS errors.

Figure 12 shows the variation of the magnitude of the angular error with respect to the beam-pointing angle for different sound speed different in SeaBat 8124 MBES. The greater the beam angle, the greater the error.

5.2 SSS Defects with Vessel Roll

The SeaBat 8124 is not a roll-stabilized transducer. Therefore with the vessel roll, the swath of this MBES moves to the side where the vessel rolls. The swath follows the roll of the vessel. Figure 13 shows the swath shape of SeaBat 8124 for +10 degrees roll angle with SSS +10m/s error.

Figure 13: SSS effects with positive roll angle.

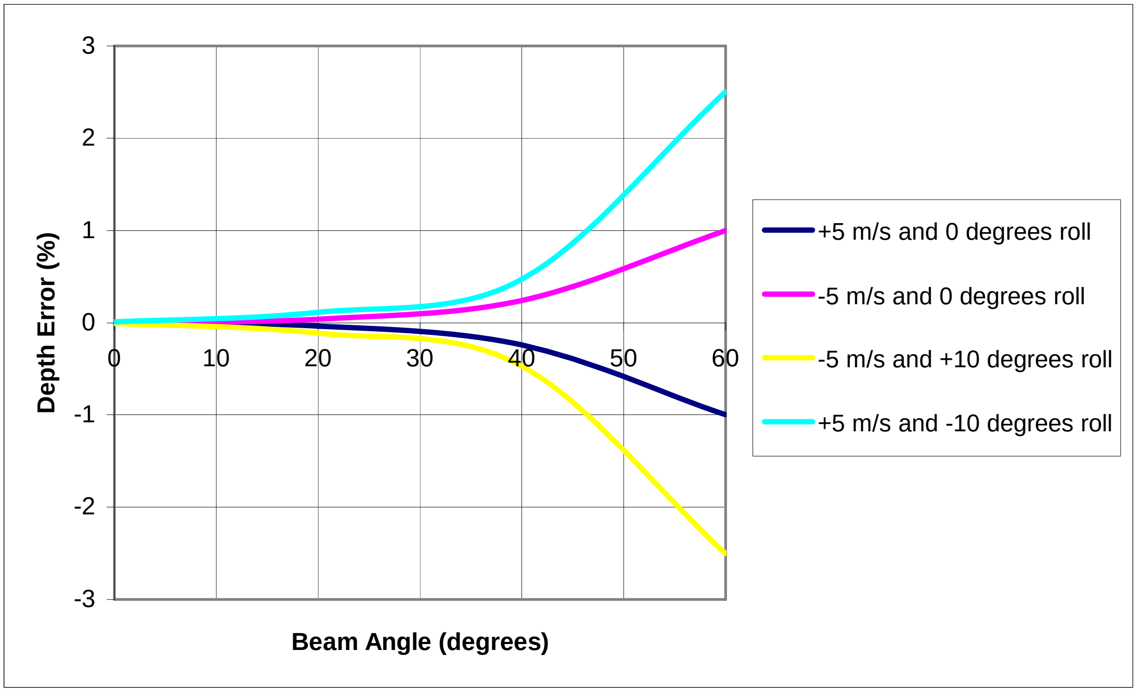


Figure 14: How SSS errors are modulated by vessel roll.

This figure shows the shape of a flat floor seen by SeaBat 8124 MBES in the following cases: +/- 5 m/s SSS errors are plotted in the same graph with +/- 10 degrees roll having the same SSS error. The effects increase with the beam angle.

5.3 Failure of SSS Probe

If the SSS probe does not give any value or in a case of a failure of the unit, the 81P processor use 1350m/s as the SSS. This is very much less (about 200 m/s) than the true value in tropical seas like here in Malaysia. This leads to very large errors in the swath.

5.4 IHO Standards vs SSS Defects

From the above results, it is clear that with erroneous SSS (10m/s) the outer beams greater than 40 degrees do not satisfy the IHO special order and beams greater than 50 degrees do not satisfy the order-1 survey requirements.

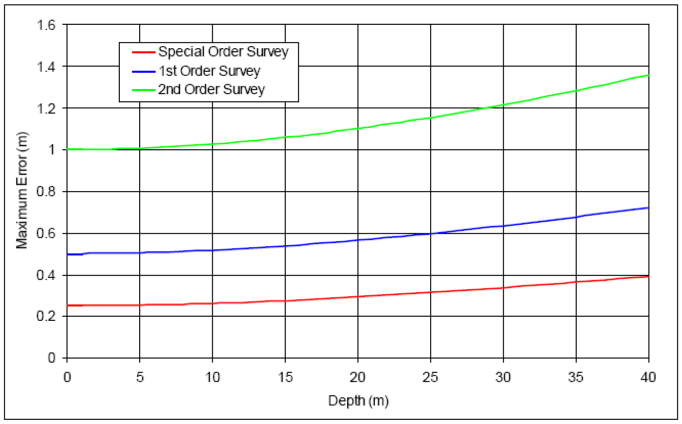


Figure 15: IHO allowable depth uncertainties.

6.0 Conclusion

1. Measurements of SSS are a must in flat array MBES for achieving high accuracy, especially in highly refractive areas like river mouth and coastal areas.
2. Any SSS failure will leads to both depth and positional accuracy of the beams.
3. If one uses a fixed value for the SSS, then try to avoid longer survey lines, to avoid crossing of different water areas.
4. In the case of the failure or bad input from the SSS unit, RESON adopt the lowest possible value of 1350m/s as the SSS, which is not a realistic value for tropical seawaters. In such cases, it should be corrected by using the surface value of most resent SSP.
5. With the vessel roll and the transducer is not roll-stabilized, the effects caused by inadequate SSS are modulated.
6. If one does not careful with the SSS, it will not satisfy the accuracy limits suggested by IHO, especially for MBES with large swath coverage.

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