Understanding the Effects of Transducer Beam Angles

CEE HydroSystems' echo sounders may be used with various 200 kHz, 33/200 kHz and 24/200 kHz survey transducers. Understanding how the transducer beam angle affects the depth measurement process is useful to understand performance limits and data artifacts. Here the topic is discussed, including an unusually extreme example from a steep sided mine pit lake survey.

Introduction

The transducer type used with an echo sounder may affect the depth data in several ways and understanding the benefits and drawbacks of different transducers is important during equipment selection. While transducers have several properties, the most important characteristic except for their operating frequency is the beam angle. Survey transducers use ceramic elements to focus a sound beam to create directional sound pulses. A narrow beam angle is more akin to a "laser beam" and a wide beam would be like a "flashlight beam" in terms of visible light. As the sonar frequency decreases, physics dictates that a transducer's diameter must increase to obtain the same beam angle. So, dual frequency transducers with a low frequency element are always much larger than typical 200 kHz single frequency transducers. Dual frequency transducer design is a compromise between portability / size and the achieved beam angle.

Survey echo sounders need to measure the depth precisely directly under the boat, by looking for the first return of sonar energy – irrespective of where that comes from within the beam. If the beam angle is wide, a much larger area of the bottom is ensonified and the potential for error in reported depth might increase. This is most problematic on steep slopes or when mapping submerged structures. The variation in ensonified area for various transducer frequencies is shown below.

Depth	*3 Degree 200kHz*	*9 Degree 200 kHz*	*19 Degree 33 kHz*	*24 Degree 24kHz*
1m	0.05m	0.16m	0.33m	0.42m
2m	0.10m	0.31m	0.65m	0.85m
3m	0.14m	0.47m	0.98m	1.27m
4m	0.19m	0.63m	1.30m	1.69m
5m	0.24m	0.78m	1.63m	2.11m
10m	0.45m	1.56m	3.26m	4.23m
20m	0.96m	3.13m	6.51m	8.45m
30m	1.44m	4.69m	9.77m	12.68m
40m	1.92m	6.26m	13.02m	16.90m
50m	2.40m	7.82m	16.28m	21.13m
100m	4.80m	15.64m	32.56m	42.26m
200m	9.60m	31.29m	65.11m	84.52m

Figure 1. Ensonified area beam diameter for various transducers

Surveying on Slopes

For a relatively flat bottom surface, the reflected sonar energy from the emitted ping will first be received from the nadir of the beam (the “first return”), and then slightly later from the edges of the beam “last return”, and these returns will be very close together. The echo sounder is always looking to detect the first return as the bottom, and if the surface is relatively flat under the boat then that will always be at the nadir. When working on slopes, it is possible for the first return to no longer be at nadir directly under the boat, as the outer edge of the beam may have a lower slant range to the bottom. In this case the depth is underestimated with the potential error increasing with depth as the ensonified bottom area diameter increases. Figure 2 depicts actual beam angles to scale, with relative errors compared for two cases. On the left, the extreme slope results in a large depth error. On the right, a low frequency 24kHz or 33kHz beam may show a noticeable error while the 200 kHz beam may have no significant error. The difference in beam angles between the low and high frequency elements in a dual frequency transducer causes divergence in the depth results as the slope increases with the low frequency becoming increasingly inaccurate.

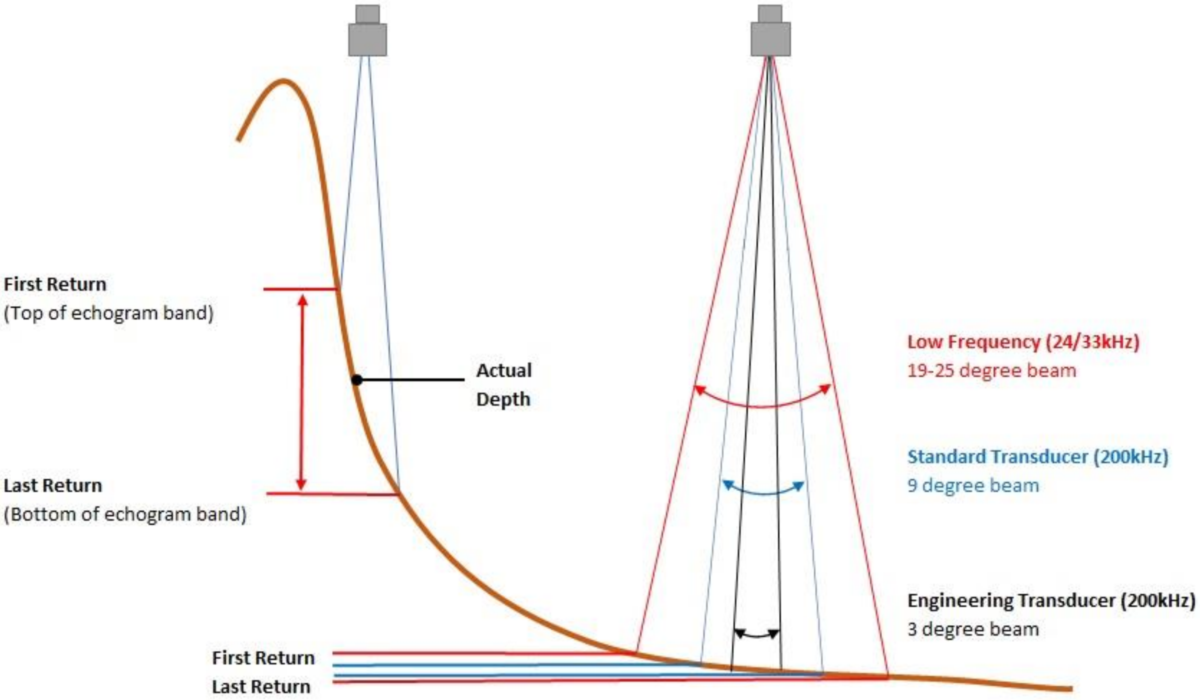

Figure 2. The effect of beam angle on measured depths

Surveying Close to Structures – Bridge Piers

One common example of a need to consider the effects of transducer beam angle is surveying near vertical structures such as bridge piers. As shown on Figure 3, below, if any of the sonar beam impinges on the structure, the depth result will be invalid as the first return will be from the structure and not the bottom and the echo sounder will record the incorrect depth. In this case then, the sonar beam angle limits how close one may survey next to the pier - this is a good time to use a narrow beam transducer that allows surveying right up to the pier.

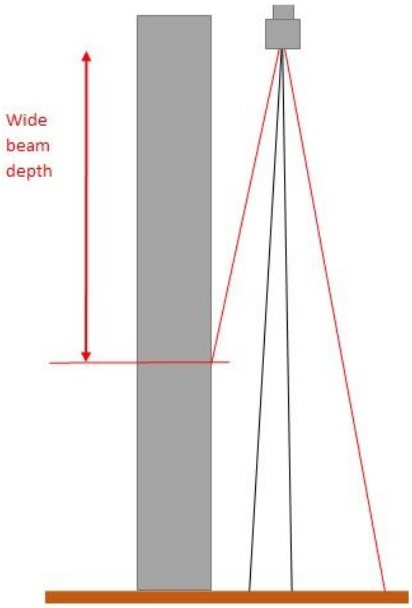

Figure 3. Narrow and wide beam transducers close to a bridge pier

Data Examples – 200 kHz Transducers

The time between the first and last return is shown by the echo sounder as the thickness of the echogram band representing the bottom. At the top of the band is the first return and the bottom is the last return. Of course, band thickness may also be affected by penetration of the sonar energy through the mud and other factors such as vegetation. In the first echogram example shown in Figure 4 below, a 200 kHz 9 degree beam transducer is used and the survey passes over a weir. The structure is large compared to the beam diameter and data are well resolved. On Figure 5, a 3 degree transducer passes over a river channel, and the consistently low echogram thickness highlights the additional precision obtained at the lower beam angle in this data.

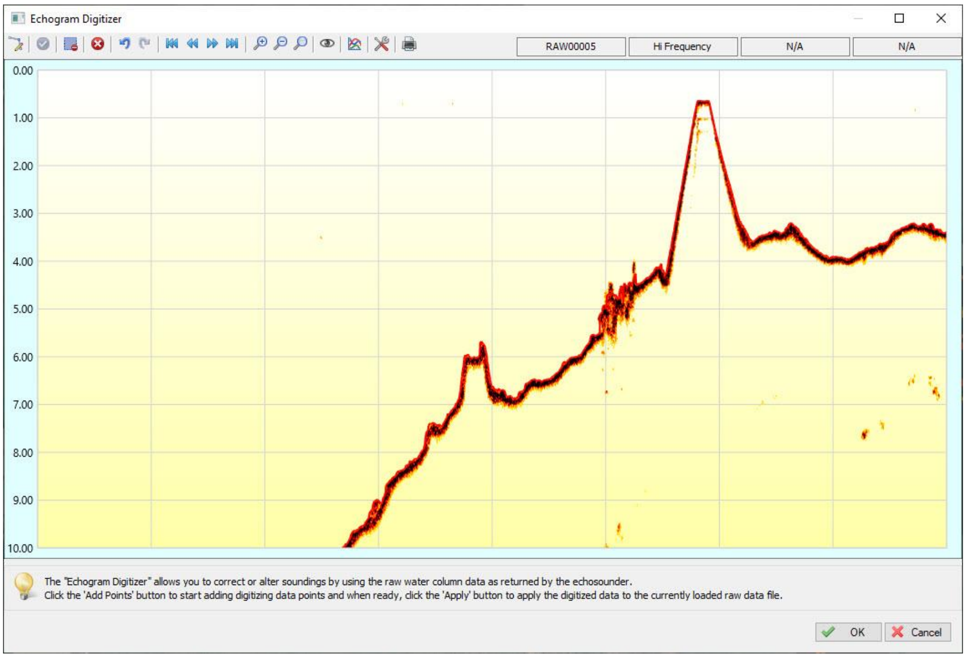

Figure 4. Water column echogram – standard 9 degree transducer

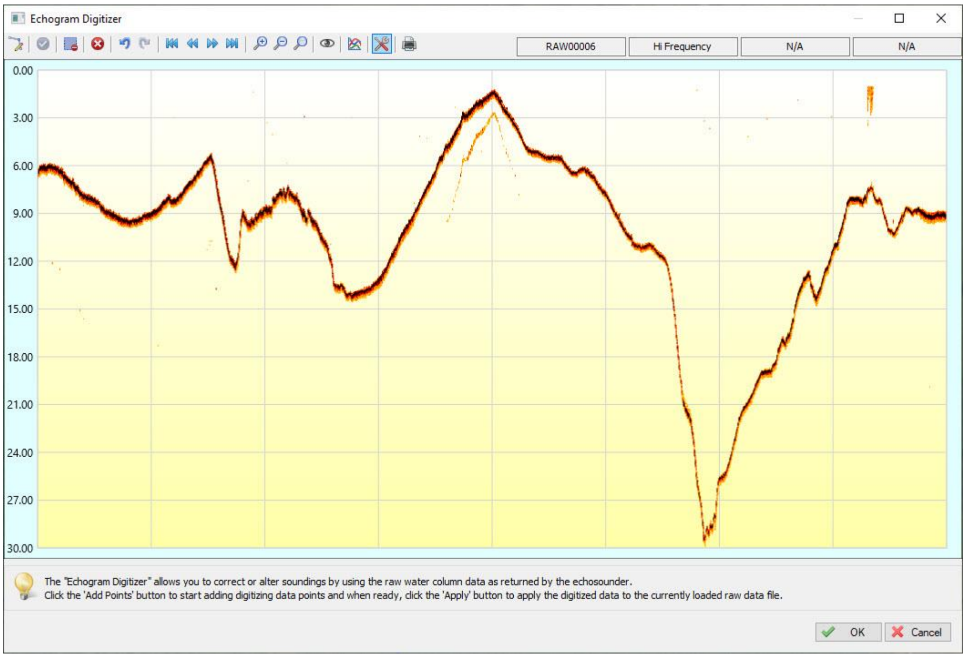

Figure 5. Water column echogram – narrow beam 3 degree transducer

Extreme Example – 33 kHz Unmanned Survey in a Mine Pit Lake

To demonstrate the impact of transducer beam angle in an extreme survey environment, a CEE-USV™ unmanned survey dataset provides an unusual example. As can be seen in Figure 6, below, the surveyed pit lake consists of a series of slopes and benches with a high gradient. After becoming inactive, the pit slowly fills with acid leachate solution forming the pit lake. In this case, thoughtful transducer selection would identify the need for a narrow beam 200 kHz transducer to accurately survey these steep slopes. Unfortunately, the pH 2.5 leachate absorbs strongly at this frequency, leading to a maximum surveyable depth of under 20ft with any 200 kHz transducer! To penetrate through to the bottom at over 100ft (30m) depth, a more powerful 33 kHz transducer with a wide 25 degree beam angle was the only option for surveyors.

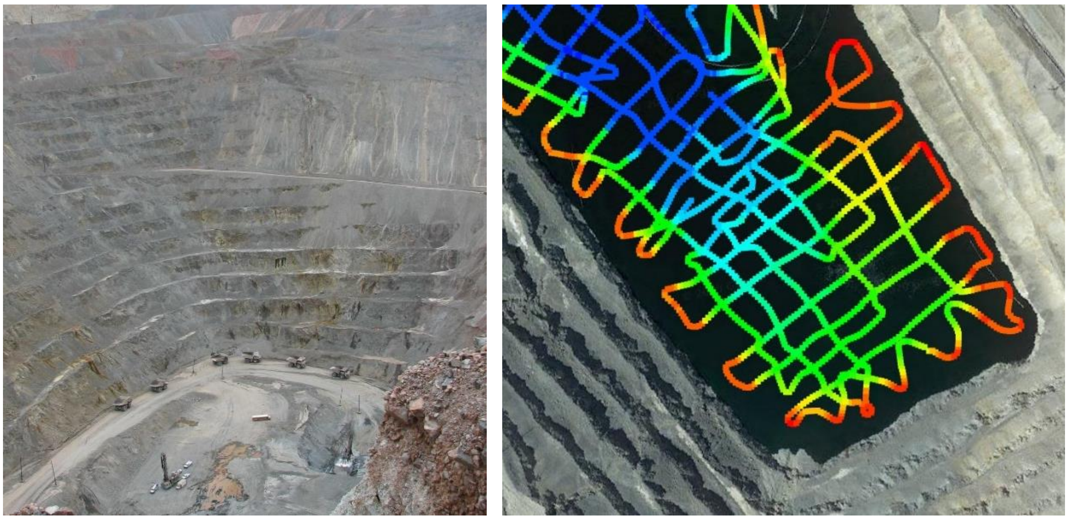

Figure 6. Southeastern USA copper mine pit lake before filling with leachate (left) and after (right)

The echogram trace from part of the survey is show in Figure 7, below. The poorly defined slopes are the result of the wide transducer beam hitting the slope over a huge depth range simultaneously. The depth errors are obvious if a vertical line is drawn from the top of the echogram return to the bottom along the slope. While in operation, the echo sounder's digitization algorithm may not mark the very first return as the bottom depth if the signal is very weak, there will nevertheless be a significant underestimation of the true depth.

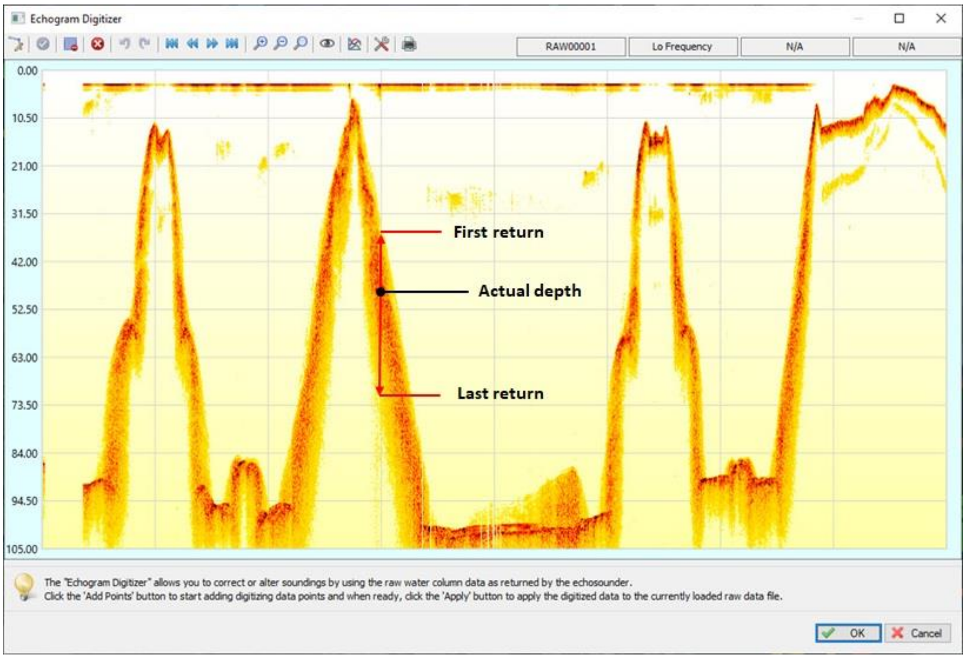

Figure 7. Water column echogram showing "fuzzy" 33 kHz bottom trace over pit wall and benches

As the boat passes over the benches (narrow flat sections), these are not well resolved as the wide beam is also simultaneously impinging on the pit wall, although the benches are clearly present in the data. The pit floor is well resolved outside of the influence of the walls. So, with the echo sounder looking for the first return as the bottom depth, the overall impact on the survey is for the reported depths along all the slopes to be significantly shallower than reality. This depth error is independent of the direction of travel of the boat relative to the slope and will cause a subsequent underestimate of the volume in the pit lake. In this case, the potential error was still acceptable for the survey goals as just being able to obtain the close approximation of volume of acid leachate was an achievement.