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IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Sound Velocity Profile (SYP) at Strait of Malacca for Maritime Warfare Usage

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DOI: https://doi.org/10.30880/ijie.2020.12.05.014
Received 21 May 2020; Accepted 28 May 2020; Available online 30 June 2020

Abstract: Nowadays, many tragedies and accidents happen in the oceans due to human negligence in handling equipment and also the ship itself. Therefore, it is important to do the hydrographic survey as it is the study about the physical of the sea. In the other words, the hydrographic survey also comes out with the prediction of their change over time, for the primary purpose of safety of navigation and in support of all other marine activities, including the economic development, security and defences, scientific research, and environmental protection. The sound velocity profile is a plot of propagation speed or velocity of sound as a function of depth and it is a fundamental tool for predicting how the sound will travel. The sound velocity profiles around the world are different. There are three factors affecting the sound velocity profile which is temperature, salinity, and pressure. The survey to get the sound velocity profile is using the sound velocity probe. The survey was done at 9 chosen locations at Straits of Malacca to get their sound velocity profile. The data from the sound velocity probe from the survey being collected by the hydrographic department and the sound velocity profile for 9 chosen locations at Straits of Malacca have been plotted. Therefore, the profile can be used as a reference for the tactical warfare usage and also for calibration of the echo sounder on board the ship.

Keywords: sound velocity profile, hydrographic survey, sound velocity probe

1. Introduction

1.1 Hydrographic Survey

Hydrographic survey is well-known activities that deal with the physical features of oceans, seas, coastal areas, lakes and river which applied in the measurement and description. Whereas the hydrographic survey is also important for the purpose of safety of navigation for ships and submarines also in tactical warfare. The hydrographic survey also supports all other marine activities, including economic development, security and defence, scientific research, and environmental protection. Sound Velocity Profile (SVP) also a survey done under the hydrographic survey [1-2]. A sound velocity profile is the plot of propagation speed (velocity) as a function of depth and it is a fundamental tool for predicting how the sound will travel. The sound velocity profile can be affected by three factors which are the temperature of water, pressure of the water as its going down to the bottom and the salinity of the water. The equipment being used to do the

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survey is a sound velocity profiler or probe. The probe is very independent and semi-autonomous equipment as it can detect those three factors that affecting the sound velocity profile by the sensors and record the data. The probe also completes with the computer-based and deployment systems to key in the data automatically when the probe launch into the water. As the sound velocity profile is used as a reference for safe navigation and warfare usage, the accuracy of the profile is important. The less accuracy of the profile may give a big bad impact for the user. The accuracy of the profile is depending by the factors those affecting the sound velocity. The sound velocity profile is well-known as a reference for tactical warfare at sea by the ship in order to reach their target accurately and for navigation used. As the sound velocity profile are affected by the three factors which are temperature, pressure, and salinity, so those factors become the limiting factor to achieve the uniform sound velocity profile over the world. The problem to get the uniform sound velocity profile for example between around the Equator and the European is because of the difference in climate, temperature, pressure, and salinity also affected [3. Thus, it is important to do the hydrographic survey in order to get the sound velocity profile for the use of navigation and also tactical warfare in Strait of Malacca.

1.2 Strait of Malacca

Strait of Malacca is a well-known strait that being used for safe passage for the mariners travel over the world. Strait of Malacca is a narrow strait with the length of 805km about 500 nautical miles. The strait is stretch of water between Peninsular of Malaysia and Sumatera Island of Indonesia. Based on the historical review, the strait is named after the Malacca sultanate the archipelago between 1400 to 1511. The strait used for main shipping channel between the Indian Ocean and the Pacific Ocean, linking the major Asian economies including India, Pakistan, China, Japan, Taiwan, and South Korea.

1.3 Sound Velocity Profile

The sound velocity profile is a plot of propagation speed or velocity of sound as a function of depth and it is a fundamental tool for predicting how the sound will travel. The sound velocity profiles around the world are different. It is because of several factors that affect the sound velocity profiles of the water. The sound that travels through salt water at about 1500 m/s where it is free of air bubbles or suspended sediment. The sound velocity profile is mainly used in navigation for calibration of the echo sounder whether it is a single beam or multibeam system [5]. Other than that, the profile also used for tactical warfare especially during launching the missile and torpedo. The speed of sound in seawater affected by the temperature, pressure, and salinity of the water. Those are the major factors that affect the sound velocity profile such as pressure, temperature and salinity of the water [6-8].

The pressure may affect sound velocity as the deeper the speed sound travels into the water the higher the pressure of the water. The approximation of speed increase is about 1.7 m/s per 100-meter change in depth (10 atm's pressure). Pressure is typically measured in decibars. One decibar pressure increase corresponds to 1 meter of water depth. As the approximation at 1ºC change of temperature in seawater will increase 4 m/s of the speed of sound. The influences on the temperature component of sound velocity including the solar heating, nighttime cooling, rain or runoff and also upwelling. Temperature also the major influenced in seawater. As the temperature is a dominating factor on the upper layer, but as the sound travelling and passed the surface, the temperature of the water will decrease until the minimum level (thermocline) and pressure will become the dominating factor towards the sound velocity [9]. Several influences on the salinity concentration in seawater are the evaporation process, precipitation process, freshwater influx from rivers and the tidal effect (salt wedges). The generally known salinity ranges of seawater are 32-38 parts per thousand (ppt) in seawater. The changes in salinity will also change the density of the water, as higher the salinity, the density will also higher. As the approximation, the changes of salinity of only 1 ppm will affect the changes of sound velocity at 1.4 m/s [10].

1.4 Sound Velocity Probe

Sound velocity probe is a device that is used for measuring the speed of sound specifically in the water column for oceanographic or hydrographic research purpose. The probe is self-contained equipment which it constitutes a complete and independent unit in and of itself. It is also not dependent on others. The probe also semi-autonomous equipment that is capable of sensing its environment and navigating without human input. It is complete with computer system based winch and also the deployment system. The data detected by the probe then being transferred automatically into the computer system through the cable [11-12].

Sound velocity probe has a velocimeter that operates on the "sing-around" sound principle and contains a transducer head and a reflective plate a known distance apart. The free-fall and retrieval interval is set by the operator for optimal data acquisition. Sound velocity profilers are capable of measuring continuous sound velocity data which increase the accuracy of hydrographic soundings. "Sing-around" principle is the use of a transducer and reflective-plate pair that is a known distance apart. The device calculates the speed of sound in water by effectively dividing this known distance by one-half the time required for a signal to be transmitted by the transducer, reflected by the reflective plate and received by the transducer.

A sound velocity probe is launched by dropping it into the water and lowered to the seafloor and then raised back up to take two casts of data which is downcast and upcast. During lowered down to the bottom, the probe takes temperature readings, salinity readings and pressure readings per time that was set by the surveyor. The data is then directly transferred into the computer system through the cables. This data is then processed in order to give the sound velocity versus water depth. Sound velocity profile should be collected as often as operationally possible to minimize the uncertainty with respect to the water column throughout the survey area.

2. Methodology

2.1 Study Area

The hydrographic survey is done by the Hydrographic Department in order to get the sound velocity profile of seawater above a stated datum and the position of the measured depth in the 9 chosen locations at Straits of Malacca. The data from the sound velocity profile (SVP) probe is given by the Hydrographic Department based on their survey done at 9 chosen location at Straits of Malacca as in Fig. 1.

Fig. 1 - The map of SVP locations

The hydrographic survey process is divided into five major stages whereas each stage divided into a number of groups of instructions or procedures as in Fig. 2. This section contains wide guidelines that relate to each of these stages.

2.2 Preparation

During the preparation stage, the planning of the survey should be done by extracting the current survey data from existing sources and plan the next observations. Calibration also needs to be done for the elimination of systematic errors on survey equipment to avoid any errors in the results. Calibration of ancillary equipment, for example, SVP probes should be carried out by the equipment manufacturer or agent in accordance with manufacturers guidelines and copies of subsequent certificates retained in the equipment data pack.

2.3 Data Collection

Verification of the instruments is important as to ensure instruments are collecting data to correct standard during survey operations. The data collection, including those observations that necessary for ongoing validation, should be done during the observation. The most important is to ensure appropriate data is logged to correct parameters during data logging.

2.4 Data Processing

During the data processing, the first step is to make the cleaning data by analyzing the data collected from equipment used and those invalid data will be removed. The valid data then be used to calculate the depth for every reading of sound velocity.

The formula created by Medwin (1975) can be used to measure the depth. The study done because of the difficulties in measuring the sound velocity, it is easier to calculate using the parameters that can affect it which is temperature, salinity, and pressure. The formula is limited to 1000 meter in depth only [3]. The formula is as below:

$$z = \frac{c - 1449.2 - 4.6t + 0.055t^2 - 0.00029t^3 - 1.34S + 56.9 + 0.01St - 0.35t}{0.016} \quad (1)$$

The data then undergoes further data selection of valid data for further processing or rendering. The selected processed data will be stored in appropriate formats during data storage.

2.5 Data Analysis

The analyzing of data is to determine the quality of surveyed data via proven methods and compare with required standards and also to determine if sufficient valid data has been collected. As for this research, the depth found from the calculation will be compared to the sound velocity. The analysis done is to identify the form of a sound velocity profile at a certain location.

2.6 Data Rendering

The report should be written as to filing the survey process and results to provide adequate transparency. The plotting activities should be done to render data as graphics as required. To render or archive digital data and to render or archive field records [2].

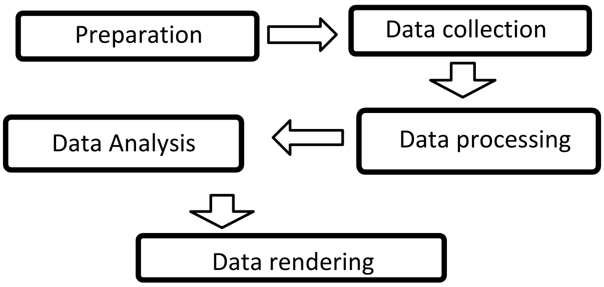

Fig. 2 - The research procedure for the sound velocity profile at Straits of Malacca

3. Results and Discussion

There are 9 locations that were chosen by the Hydrographic Department for surveying. The survey is done early in the morning around 0700 H to 0800H and in the evening around 1800 H to 1900H. The temperature of the water is the dominant factor which affects the sound velocity in the water. This time frame is chosen because of the temperature during that time is optimum to get the best reading of sound velocity of the seawater. The 9 locations of a survey done in the area of Pulau Perak with latitude 5° 42’ N and longitude 98° 56’ E. Every location is shown different sound velocity profile because of the factors that affect the sound velocity at the location itself. These are the data analysis in the form of a sound velocity profile for 9 locations:

3.1 Location 1

In Fig. 3 shows that the sound velocity versus depth of water at location 1 during downcast. The sound velocity at the surface is 1540.965 m/s. As the sound velocity probe going down into the sea, there are only small changes to the sound velocity at 50 m and below. The rapid change can be seen at depth of 60 m to 80 m. During downcast, the highest sound velocity is 1542.025 m/s at 37 m. At 10 m, the sound velocity is 1541.559 m/s. Sound velocity decrease to 1541.416 m/s at 20m depth. Then, slightly increase to 1541.514 m/s at 30m. Sound velocity continues to increase to 1541.852 m/s at 40m. At 50 m, sound velocity starts to decrease again to 1541.533 m/s. The sound velocity then decreases to 1538.036 m/s at 60 m depth. At 70m depth, the sound velocity decrease more to 1528.293 m/s. Lastly, the lowest sound velocity during downcast 1519.983 m/s at 83 m. So, there is a slow declination of the sound velocity from the surface to 50 m depth and rapid declination from 60 m to 80 m depth.

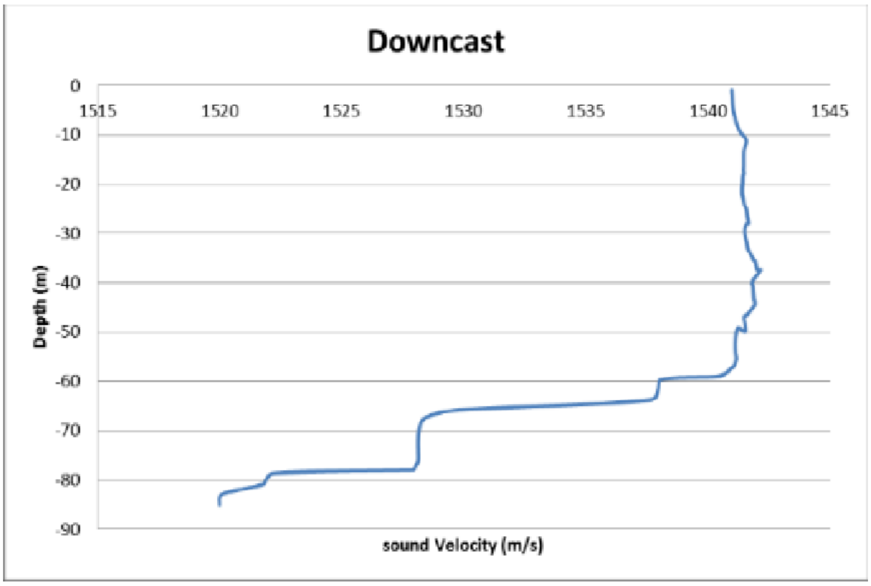

Fig. 3 - The sound velocity profile during downcast at Lat: 05° 53.55'N, Long: 098° 30.46' E

From Fig. 4 it shows the sound velocity profile during upcast of the sound velocity probe where the probe is starting to be pulled back to the surface. The sound velocity at 98 m is starting to increase to 1520.132 m/s. The rapid changing where the sound velocity seems to increase from the deeper water up to 60 m. Then, the sound velocity is slightly maintained going up to the surface of the water. At 80 m depth, the sound velocity is 1528.342 m/s. The sound velocity increase to 1537.958 m/s at 70m depth. Then, increase to 1541.106 m/s at 60 m depth. While at 50 m, the sound velocity slightly increases to 1541.545 m/s. A small increase of sound velocity at 40 m which is 1541.855 m/s. The sound velocity slightly decreases at 30 m depth to 1541.636 m/s. At 20 m depth, sound velocity decrease to 1541.367 m/s but increase back to 1541.844 m/s at 10 m. The highest sound velocity is at the surface of the water which is 1542.546 m/s.

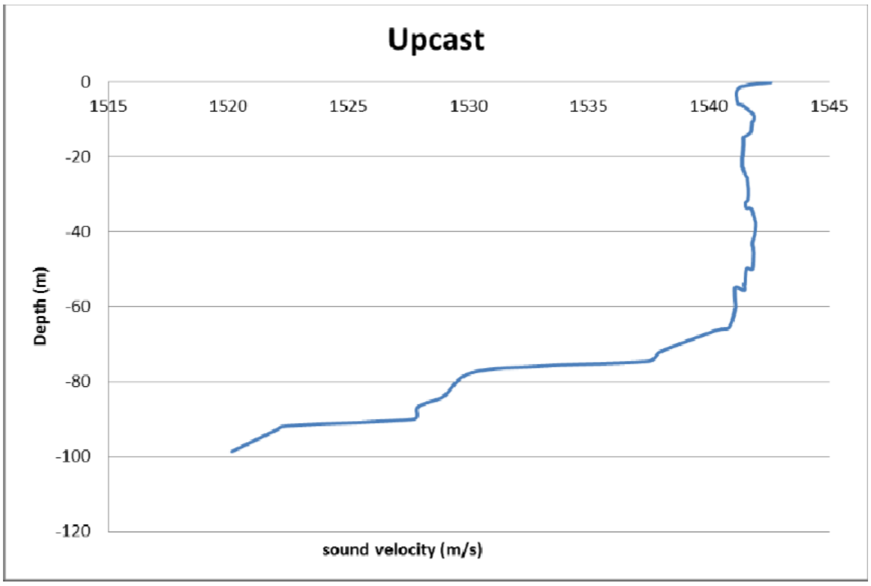

Fig. 4 - The sound velocity profile during upcast at Lat: 05° 53.55'N, Long: 098° 30.46' E

3.2 Location 2

In Fig. 5 it shows that the sound velocity during downcast at location 2. The sound velocity at the surface is 1541.5 m/s. As the sound velocity probe going down into the water body, it shows that the sound velocity at 50 m and below is slightly maintain. The rapid change can be seen at 50m depth to 80 m depth. During downcast, the highest sound velocity is 1542.24 m/s at 41 m. At 10 m, the sound velocity is 1541.618 m/s. Sound velocity decrease to 1541.616 m/s at 20m depth. Then, decrease to 1541.608 m/s at 30m. Sound velocity slightly increases to 1541.881 m/s at 40m. At 50 m, sound velocity starts to decrease again to 1541.42 m/s. The sound velocity is then decreased to 1538.571 m/s at 60 m depth. At 70m depth, the sound velocity decrease more to 1527.284 m/s and continue decreasing to 1522.005 m/s at

80m. Lastly, the sound velocity reached the lowest during downcast is 1522.002 m/s at 83 m. So, there is a slow declination of the sound velocity from the surface to 50 m depth and rapid declination from 60 m to 80 m depth.

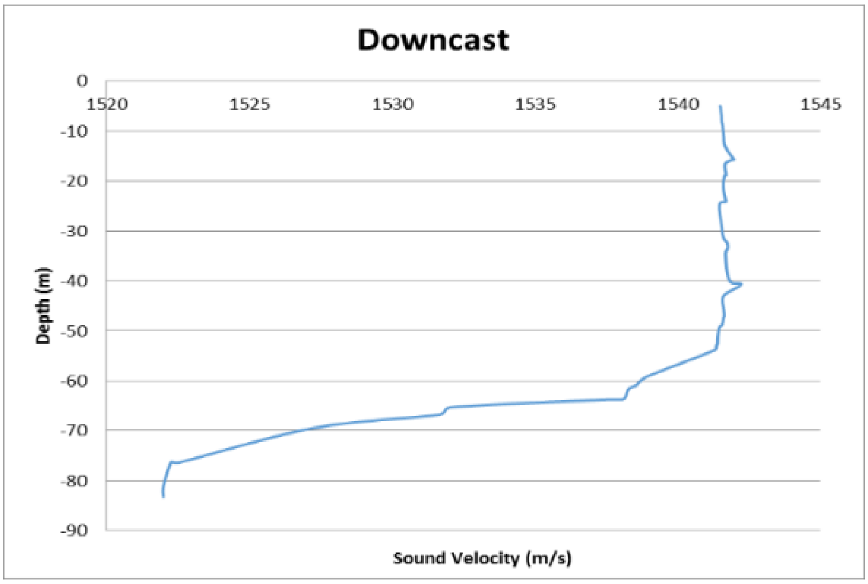

Fig. 5 - The sound velocity profile during downcast at Lat: 05° 52.54' N, Long: 098° 26.38' E

From Fig. 6, it shows the sound velocity profile during upcast of the sound velocity probe where the probe is starting to be pulled back to the surface. The sound velocity at 80 m is starting to increase to 1536.693 m/s. The rapid changing where the sound velocity seems to increase from the deeper water up to 60 m. Then, the sound velocity is slightly maintained going up to the surface of the water. At 70 m depth, the sound velocity is 1538.03 m/s. The sound velocity increase to 1541.211 m/s at 60m depth. Then, increase to 1541.499 m/s at 50 m depth. While at 40 m, the sound velocity slightly increases to 1541.547 m/s. A small increment of sound velocity at 30 m about 0.265 m/s which is to 1541.764 m/s. The sound velocity slightly decreases from 20 m depth to 1541.592 m/s but increase back to 1541.596 m/s at 10 m. The sound velocity at the surface of the water is 1541.5 m/s. The highest sound velocity is 1541.742 m/s which is at 34 m depth.

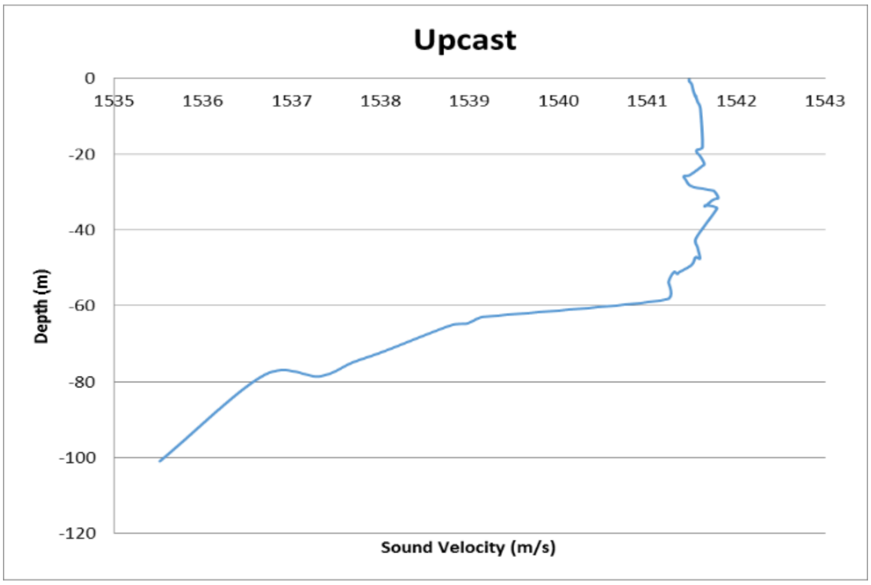

Fig. 6 - The sound velocity profile during upcast at Lat: 05° 52.54' N, Long: 098° 26.38' E

3.3 Location 3

In Fig. 7 it shows that the sound velocity during downcast at location 3. The sound velocity at the surface is 1542.013 m/s. As the sound velocity probe going down into the water body, it shows that the sound velocity at 50 m and below is slightly maintain. The rapid change can be seen after passing 50 m and going deeper to 80 m. During downcast, the highest sound velocity for location 3 is at the surface of the water. At 10 m, the sound velocity is 1541.926 m/s. Sound velocity decrease to 1541.676 m/s at 20m depth. Then, increase to 1541.774 m/s at 30m. Sound velocity decrease to 1540.081 m/s at 40m. At 50 m, sound velocity decrease more to 1539.92 m/s. The sound velocity is then rapidly decreasing to 1533.344 m/s at 60 m depth. At 70m depth, the sound velocity decrease more to 1529.619 m/s. Lastly, the sound velocity reached the lowest during downcast is 1518.208 m/s at 80 m. So, there is a slow declination of the sound velocity from the surface to 50 m depth and rapid declination when probe going down to the water from 50 m to 80 m depth.shows that the sound velocity versus depth of water at location 1 during downcast.

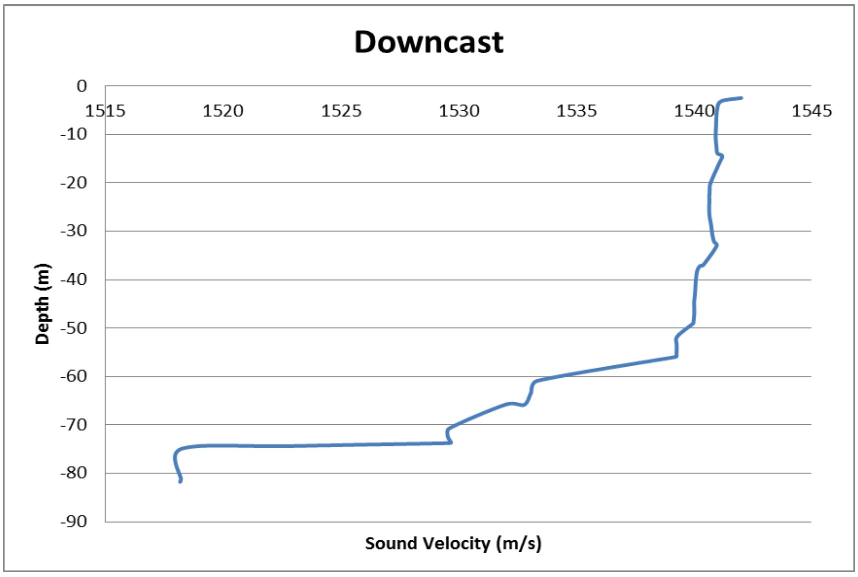

Fig. 7 - The sound velocity profile during downcast at Lat: 06º 04.32' N, Long: 098º 26.38'E

From the Fig. 8 shows the sound velocity profile during upcast of the sound velocity probe where the probe is starting to be pulled back to the surface at location 3. The sound velocity at 99 m is starting to increase to 1521.143 m/s. The rapid changing where the sound velocity seems to increase from the deeper water up to 60 m. Then, the sound velocity is slightly maintained from 60 m going up to the surface of the water. At 80 m depth, the sound velocity is 1529.192 m/s. The sound velocity increase to 1529.797 m/s at 70m depth. Then, increase to 1539.151 m/s at 60 m depth. While at 50 m, the sound velocity slightly increases to 1539.989 m/s. A small increase of sound velocity at 40 m which is 1540.428 m/s. The sound velocity continues to increase at 30 m depth to 1540.719 m/s. At 20 m depth, sound velocity keeps increasing to 1540.738 m/s and increase more to 1540.922 m/s at 10 m. The highest sound velocity is at the surface of the water which is 1542.079 m/s.

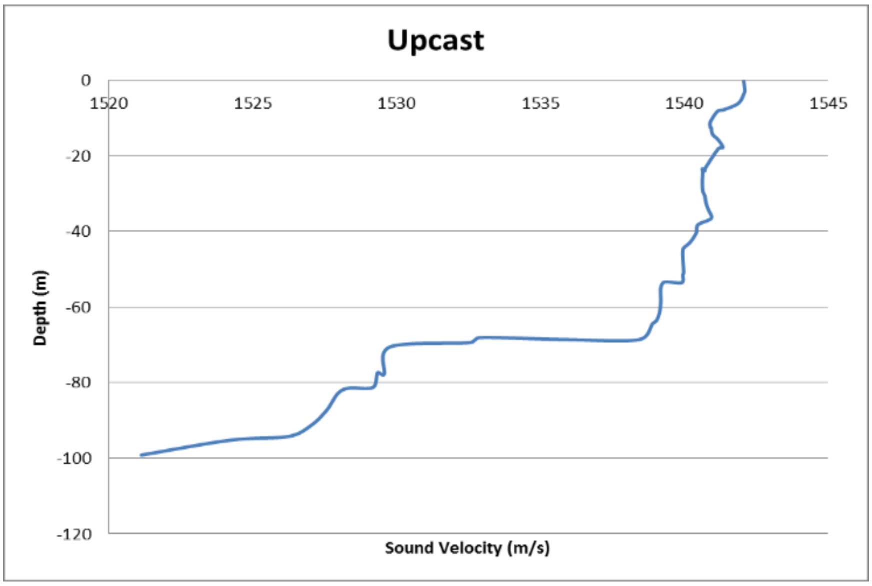

Fig. 8 - The sound velocity profile during upcast at Lat: 06º 04.32' N, Long: 098º 26.38' E

3.4 Location 4

In Fig. 9 shows that the sound velocity during downcast at location 4. The sound velocity at the surface is 1541.352 m/s. As the sound velocity probe going down into the water body, it shows that the sound velocity at 40 m and below is slightly maintain. The rapid change can be seen after passing 40 m and going deeper to 80 m. During downcast, the highest sound velocity for location 4 is 1541.673 m/s at 29 m. The sound velocity at the surface of the water is 1541.352. At 10 m, the sound velocity is 1541.616 m/s. Sound velocity decrease to 1541.312 m/s at 20m depth. Then, it slightly increases to 1541.673 m/s at 30 m. Sound velocity then decreases to 1540.722 m/s at 40 m. At 50 m, sound velocity decrease more to 1536.895 m/s. The sound velocity is then rapidly decreasing to 1531.867 m/s at 60 m depth. At 70m depth, the sound velocity decrease more to 1519.874 m/s. Lastly, the sound velocity reached the lowest during downcast is 1519.084 m/s at 80 m. So, there is a slow declination of the sound velocity from the surface to 40 m depth and rapid declination when probe going down to the water from 45 m to 80 m depth.

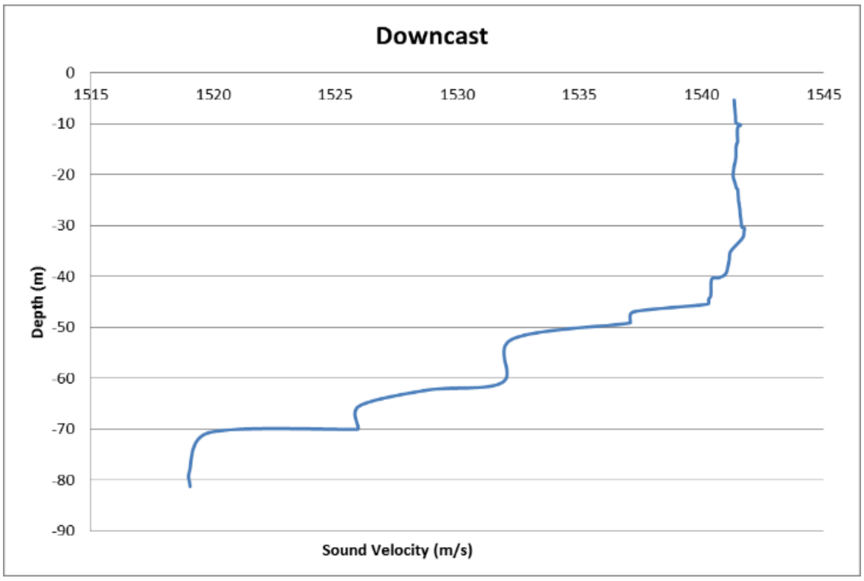

Fig. 9 - The sound velocity profile during downcast at Lat: 06º 36' N, Long: 098º 57' 46.05" E

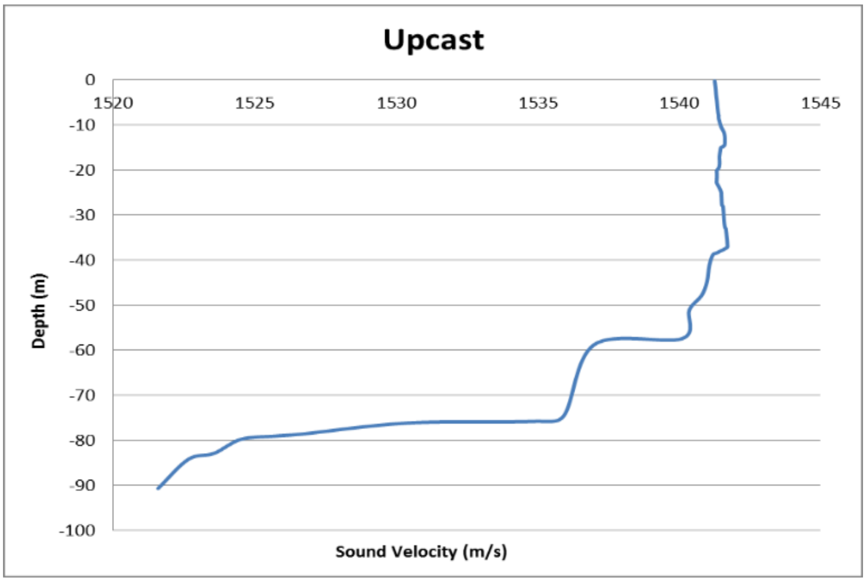

Fig. 10 - The sound velocity profile during upcast at Lat: 06º 36' N, Long: 098º 57' 46.05" E

From Fig. 10 it shows the sound velocity profile during upcast of the sound velocity probe where the probe is starting to be pulled back to the surface at location 4. The sound velocity at 90 m is starting to increase to 1521.598 m/s. The rapid changing where the sound velocity seems to increase from the deeper water up to 60 m. Then, the sound velocity is slightly maintained after passing 60 m going up to the surface of the water. At 80 m depth, the sound velocity is 1524.522 m/s. The sound velocity increase to 1538.03 m/s at 70m depth. Then, slightly decrease to 1537.023 m/s at

60 m depth. While at 50 m, the sound velocity slightly increases back to 1540.369 m/s. A small increase of sound velocity at 40 m which is 1541.076 m/s. The sound velocity continues to increase at 30 m depth to 1541.599 m/s. At 20 m depth, sound velocity decrease to 1541.343 m/s and increase more to 1541.491 m/s at 10 m. The sound velocity is at the surface of the water is 1541.249 m/s. The highest velocity during upcast at location 4 is 1541.696 m/s at 37 m depth.

3.5 Location 5

In Fig. 11 In the figure above, it shows that the sound velocity during downcast at location 5. The sound velocity at the surface is 1541.698 m/s is the highest. As the sound velocity probe going down into the water body, it shows that the sound velocity at 40 m and below is slightly maintain. The rapid change can be seen after passing 40 m and going deeper to 80 m. During downcast, the highest sound velocity for location 3 is 1541.673 m/s at 29 m. At 10 m, the sound velocity is 1540.991 m/s. Sound velocity decrease to 1540.641 m/s at 20m depth. Then, it slightly increases to 1540.704 m/s at 30 m. Sound velocity then decreases to 1540.47 m/s at 40 m. At 50 m, sound velocity decrease more to 1538.302 m/s. The sound velocity is then rapidly decreasing to 1531.794 m/s at 60 m depth. At 70m depth, the sound velocity decrease more to 1526.723 m/s. Lastly, the sound velocity reached the lowest during downcast is 1517.387 m/s at 80 m. So, there is a slow declination of the sound velocity from the surface to 40 m depth and rapid declination when probe going down to the water from 45 m to 80 m depth.

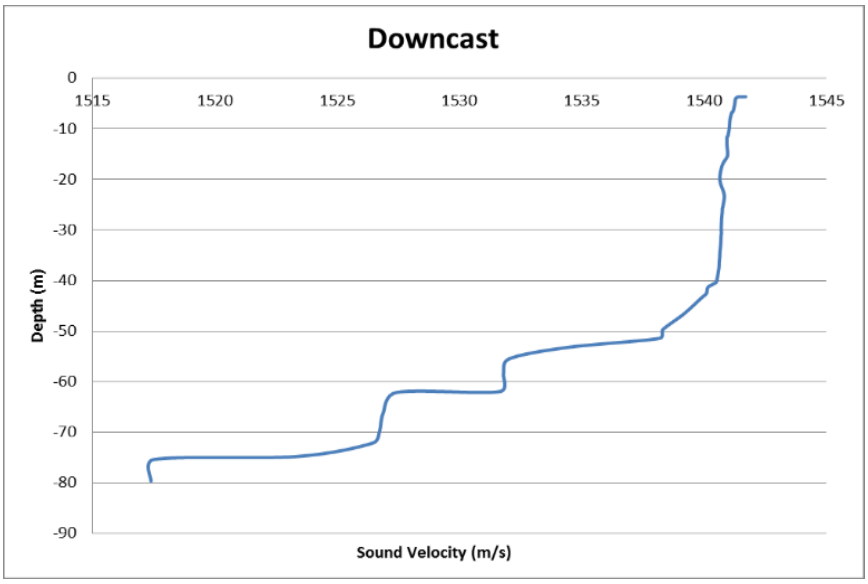

Fig. 11 - The sound velocity profile during downcast at Lat: 06° 05’ 34.33” N, Long: 098° 27’ 37.08” E

From Fig. 12 shows the sound velocity profile during upcast of the sound velocity probe where the probe is starting to be pulled back to the surface at location 5. The sound velocity at 90 m is starting to increase to 1526.572 m/s. The rapid changing where the sound velocity seems to increase from the deeper water up to 60 m. Then, the sound velocity is slightly maintained after passing 60 m going up to the surface of the water. At 80 m depth, the sound velocity is 1528.392 m/s. The sound velocity increase to 1538.848 m/s at 70m depth. Then, sound velocity keep increase to 1539.896 m/s at 60 m depth. While at 50 m, the sound velocity increase more back to 1540.369 m/s. A small increase of sound velocity at 40 m which is 1540.639 m/s. The sound velocity continues to increase at 30 m depth to 1540.79 m/s. At 20 m depth, sound velocity continues increase to 1540.932 m/s and increase more to 1540.987 m/s at 10 m. The sound velocity is at the surface of the water is 1541.113 m/s. The highest velocity during upcast at location 5 is at the surface of the water.

3.6 Location 6

In Fig. 13 it shows that the sound velocity during downcast at location 6. The sound velocity at the surface is 1541.052 m/s. As the sound velocity probe going down into the water body, it shows that the sound velocity at 50 m and below is slightly maintain. The rapid change can be seen after passing 45 m and going deeper to 80 m. During downcast, the highest sound velocity for location 3 is 1541.413 m/s at 17 m. At 10 m, the sound velocity is 1541.141 m/s. Sound velocity increase to 1541.345 m/s at 20m depth. Then, it slightly decreases to 1540.772 m/s at 30 m. Sound velocity is then a little bit increase to 1540.83 m/s at 40 m. At 50 m, sound velocity drops back to 1540.223 m/s. The sound velocity is then rapidly decreasing to 1536.533 m/s at 60 m depth. At 70m depth, the sound velocity shows the most rapid decrease to 1528.772 m/s. Lastly, the sound velocity reached the lowest during downcast is 1518.063 m/s at 80 m. So, there is a slow declination of the sound velocity from the surface to 50 m depth and rapid declination when probe going down to the water from 45 m to 80 m depth.

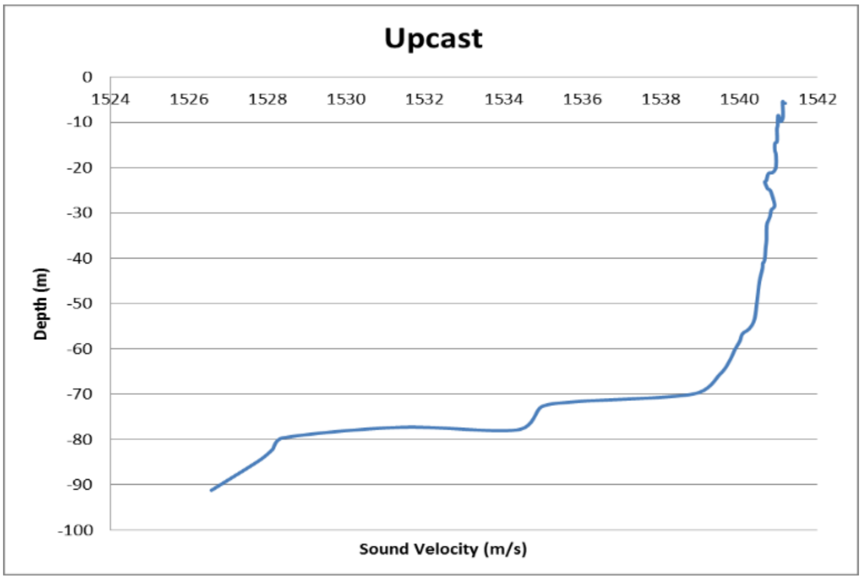

Fig. 12 - The sound velocity profile during upcast at Lat: 06° 05’ 34.33” N, Long: 098° 27’ 37.08” E

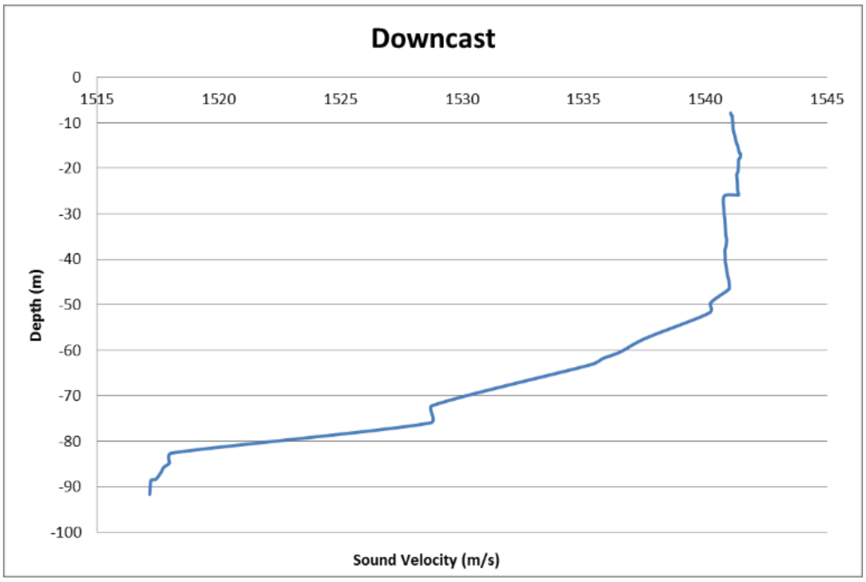

Fig. 13 - The sound velocity profile during downcast at Lat: 06° 06’ 34.33” N, Long: 098° 28’ 11.08” E

From Fig. 14 it shows the sound velocity profile during upcast of the sound velocity probe where the probe is starting to be pulled back to the surface at location 6. The sound velocity at 91 m is starting to increase to 1526.572 m/s. The rapid changing where the sound velocity seems to increase from the deeper water up to 60 m. Then, the sound velocity is slightly maintained after passing 60 m going up to the surface of the water. At 80 m depth, the sound velocity is 1536.162 m/s. The sound velocity increase to 1536.953 m/s at 70m depth. Then, sound velocity keeps the increase to 1538.4 m/s at 60 m depth. While at 50 m, the sound velocity increase more back to 1540.81 m/s. A small increase of sound velocity at 40 m which is 1540.878 m/s. The sound velocity slightly drops at 30 m depth to 1540.815 m/s. At 20 m depth, sound velocity rapidly increases to 1541.411 m/s and drop back to 1541.283 m/s at 10 m. The sound velocity is at the surface of the water is 1541.113 m/s. The highest velocity during upcast at location 7 is at the surface of the water.

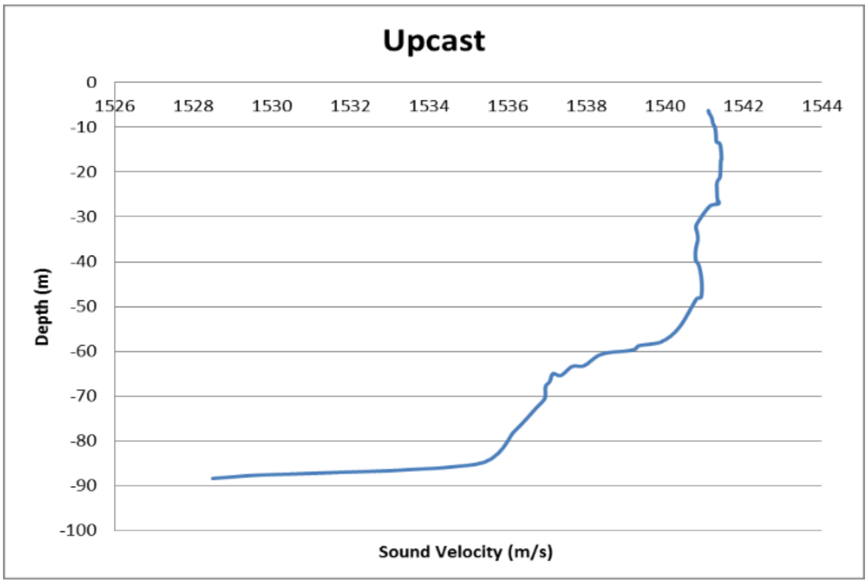

Fig. 14 - The sound velocity profile during upcast at Lat: 06° 06' 34.33" N, Long: 098° 28' 11.08" E

3.7 Location 7

In Fig. 15 it shows that the sound velocity during downcast at location 7. The sound velocity at the surface is 1541.052 m/s. As the sound velocity probe going down into the water body, it shows that the sound velocity at 50 m and below is slightly maintain. The rapid change can be seen after passing 45 m and going deeper to 80 m. During downcast, the highest sound velocity for location 3 is 1541.413 m/s at 17 m. At 10 m, the sound velocity is 1541.124 m/s. Sound velocity increase to 1541.345 m/s at 20m depth. Then, it slightly decreases to 1540.772 m/s at 30 m. Sound velocity is then a little bit increase to 1540.83 m/s at 40 m. At 50 m, sound velocity drops back to 1538.537 m/s. The sound velocity is then rapidly decreasing to 1536.533 m/s at 60 m depth. At 70 m depth, the sound velocity is the most rapid decrease to 1518.312 m/s. Lastly, the sound velocity reached the lowest during downcast is 1518.063 m/s at 80 m. So, there is a slow declination of the sound velocity from the surface to 40 m depth and rapid declination when probe going down to the water from 45 m to 80 m depth.

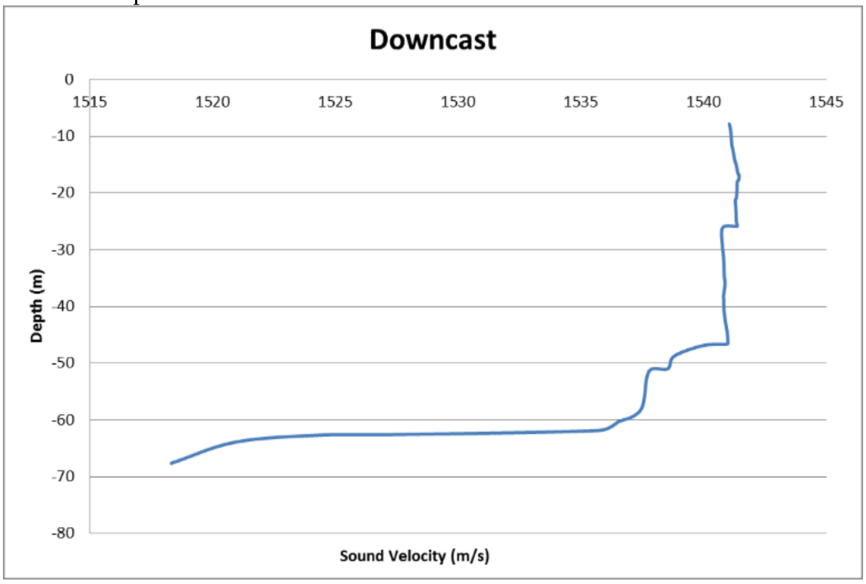

Fig. 15 - The sound velocity profile during downcast at Lat: 05° 57' 49.6" N, Long: 098° 37' 12.75" E

From Fig. 16 it shows the sound velocity profile during upcast of the sound velocity probe where the probe is starting to be pulled back to the surface at location 7. The sound velocity at 88 m is starting to increase to 1528.502 m/s. The rapid changing where the sound velocity seems to increase from the deeper water up to 60 m. Then, the sound velocity is slightly maintained after passing 60 m going up to the surface of the water. At 80 m depth, the sound velocity is 1534.851 m/s. The sound velocity increase to 1536.953 m/s at 70m depth. Then, sound velocity keeps the increase to 1539.196 m/s at 60 m depth. While at 50 m, the sound velocity increase back to 1540.934 m/s. A small increase of sound velocity at 40 m which is 1540.797 m/s. The sound velocity slightly drops again at 30 m depth to 1540.774 m/s. At 20 m depth, sound velocity rapidly increases to 1541.411 m/s and drop back to 1541.283 m/s at 10 m. The sound velocity is at the surface of the water is 1541.196 m/s. The highest velocity during upcast at location 7 is at the depth of 15 m which is 1541.435 m/s.

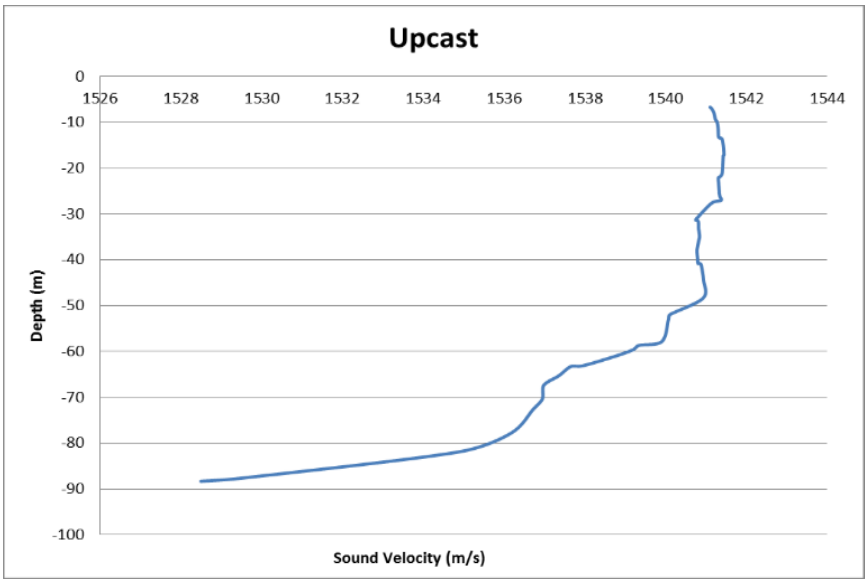

Fig. 16 - The sound velocity profile upcast at Lat: 05º 57' 49.6" N, Long: 098º 37' 12.75" E

3.8 Location 8

In Fig. 17 it shows that the sound velocity during downcast at location 8. The sound velocity at the surface is 1540.095 m/s. As the sound velocity probe going down into the water body, it shows that the sound velocity at 40 m and below is slightly maintain. The rapid change can be seen after passing 50 m and going deeper to 80 m. During downcast, the highest sound velocity for location 3 is 1541.498 m/s at 26 m. At 10 m, the sound velocity is 1541.006 m/s. Sound velocity increase to 1541.47 m/s at 20m depth. Then, it slightly decreases to 1541.137 m/s at 30 m. Sound velocity is then dropping again to 1540.976 m/s at 40 m. At 50 m, sound velocity decrease more to 1540.402 m/s. The sound velocity is then rapidly decreasing to 1536.691 m/s at 60 m depth. At 70m depth, the sound velocity is kept decrease to 1535.048 m/s. Lastly, the sound velocity reached the lowest during downcast is 1518.713 m/s at 80 m. So, there is a slow declination of the sound velocity from the surface to 40 m depth and rapid declination when probe going down to the water from 50 m to 80 m depth.

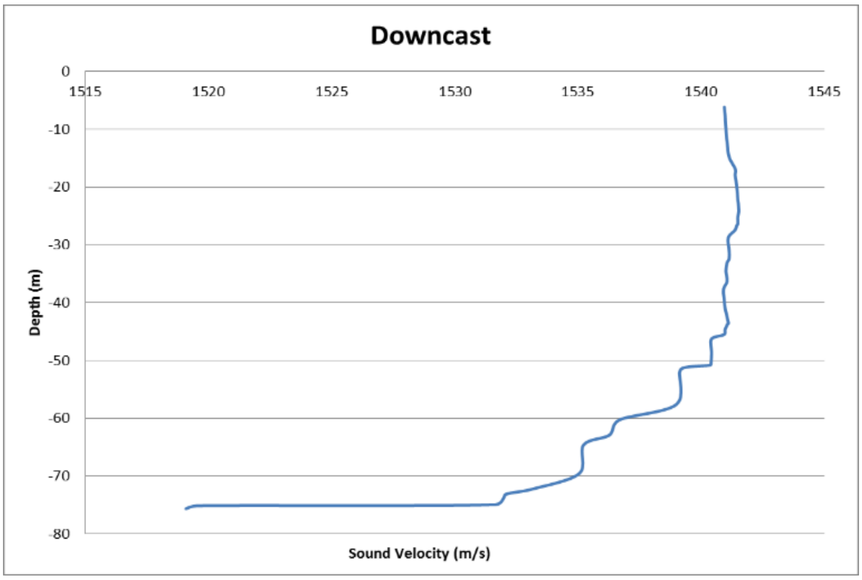

Fig. 17 - The sound velocity profile during downcast at Lat: 05° 59′36.93″ N, Long: 098º 37' 21.36"E

From Fig. 18, it shows the sound velocity profile during upcast of the sound velocity probe where the probe is starting to be pulled back to the surface at location 8. The sound velocity at 90 m is starting to increase to 1532.697 m/s.

The rapid changing where the sound velocity seems to increase from the deeper water up to 60 m. Then, the sound velocity is slightly maintained after passing 60 m going up to the surface of the water. At 80 m depth, the sound velocity is 1535.546 m/s. The sound velocity increase to 1537.337 m/s at 70m depth. Then, sound velocity keeps the increase to 1540.292 m/s at 60 m depth. While at 50 m, the sound velocity increase more to 1541.013 m/s. A small decrease in sound velocity at 40 m which is 1540.916 m/s. The sound velocity slightly increases again at 30 m depth to 1541.485 m/s. At 20 m depth, sound velocity drops again to 1541.415 m/s and drop more to 1540.975 m/s at 10 m. The sound velocity is at the surface of the water is 1540.84 m/s. The highest velocity during upcast at location 8 is at the depth of 30 m which is 1541.485 m/s.

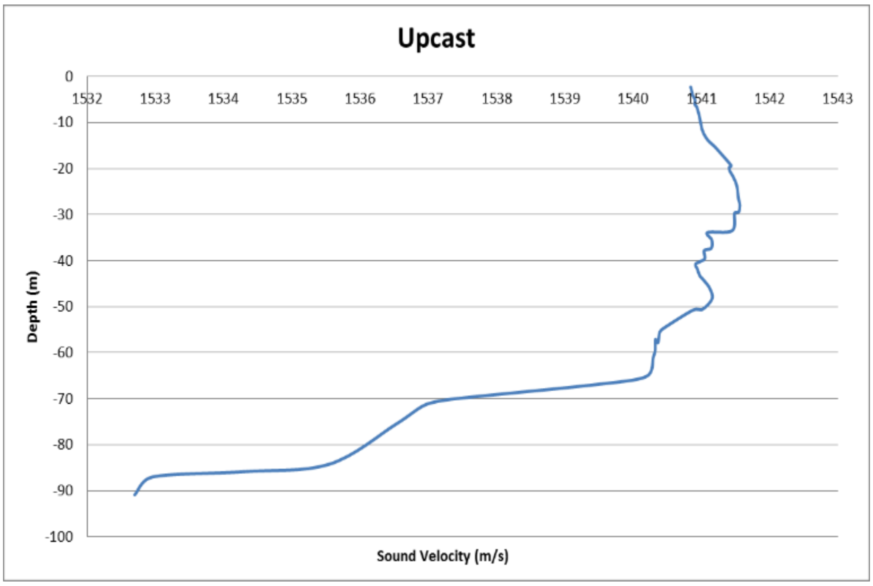

Fig. 18 -The sound velocity during upcast at Lat: 05° 59′ 36.93″ N, Long: 098° 37′ 21.36″ E

3.9 Location 9

In Fig. 19 it shows that the sound velocity during downcast at location 9. The sound velocity at the surface is 1541.301 m/s. As the sound velocity probe going down into the water body, it shows that the sound velocity at 40 m and below is slightly maintain. The rapid change can be seen after passing 50 m and going deeper to 80 m. During downcast, the highest sound velocity is at the surface of the water. At 10 m, the sound velocity is 1541.143 m/s. Sound velocity increase to 1541.17 m/s at 20m depth. Then, it slightly decreases to 1540.775 m/s at 30 m. Sound velocity is then increased back to 1541.04 m/s at 40 m. At 50 m, sound velocity decrease more to 1540.403 m/s. The sound velocity is then rapidly decreasing to 1534.837 m/s at 60 m depth. At 70m depth, the sound velocity is kept decrease to 1528.909 m/s. Lastly, the sound velocity reached the lowest during downcast is 1517.515 m/s at 80 m. So, there is a slow declination of the sound velocity from the surface to 40 m depth and rapid declination when probe going down to the water from 50 m to 80 m depth.

From Fig. 20, it shows the sound velocity profile during upcast of the sound velocity probe where the probe is starting to be pulled back to the surface at location 8. The sound velocity at 91 m is starting to increase to 1528.624 m/s. The rapid changing where the sound velocity seems to increase from the deeper water up to 60 m. Then, the sound velocity is slightly maintained after passing 60 m going up to the surface of the water. At 80 m depth, the sound velocity is 1528.823 m/s. The sound velocity increase to 1530.082 m/s at 70m depth. Then, sound velocity drops to 1539.734 m/s at 60 m depth. While at 50 m, the sound velocity increase back to 1540.956 m/s. A small increase of sound velocity at 40 m which is 1541.048 m/s. The sound velocity slightly decreases again at 30 m depth to 1540.707 m/s. At 20 m depth, sound velocity rises again to 1541.099 m/s and drop more to 1541.23 m/s at 10 m. The sound velocity is at the surface of the water is 1541.295 m/s. The highest velocity during upcast at location 9 is at the surface of the water.

3.10 Average Sound Velocity Profile

In Fig. 21 it show that the sound velocity profile is decreasing whereas the depth is increasing. The sound velocity shown in the graph above is the average velocity from those 9 locations. At 10 m, the average sound velocity is 1541.263 m/s. The average sound velocity at 20 m is 1541.238 m/s, it is a little bit increase from 10 m. The sound velocity decrease to 1541.112 m/s at 30 m. At 40 m, the sound velocity decrease more to 1540.993 m/s. The sound velocity decrease to 1540.29 m/s at 50 m depth. At 60 m, the sound velocity dropped to 1537.656 m/s and decrease more to 1531.373 m/s at 70 m. At 80 m, sound velocity decrease more to 1525.196 m/s. Therefore, as shown in the figure above, it can be concluded that the sound velocity is most obviously decline rapidly after passing 50 m depth.

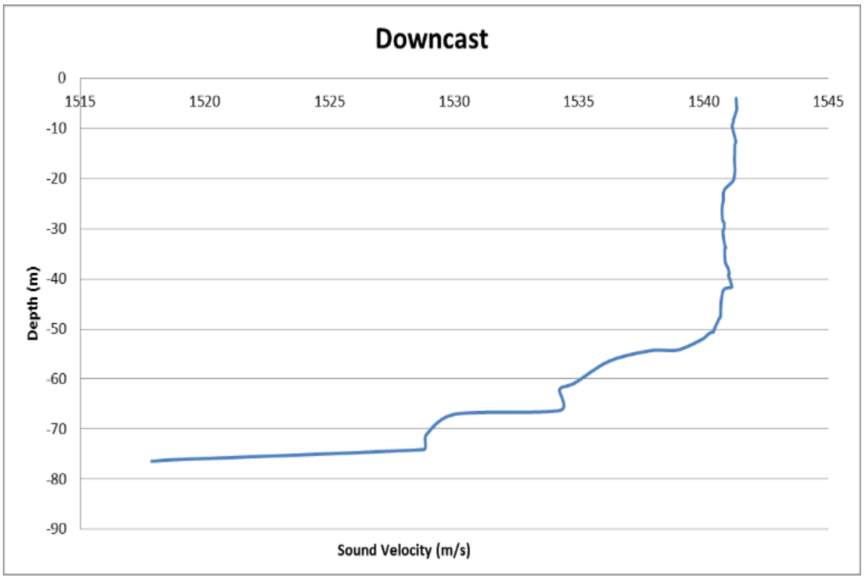

Fig. 19 -The sound velocity during downcast at Lat: 06° 11′ 56.93″ N, Long: 098° 42′ 21.36″ E

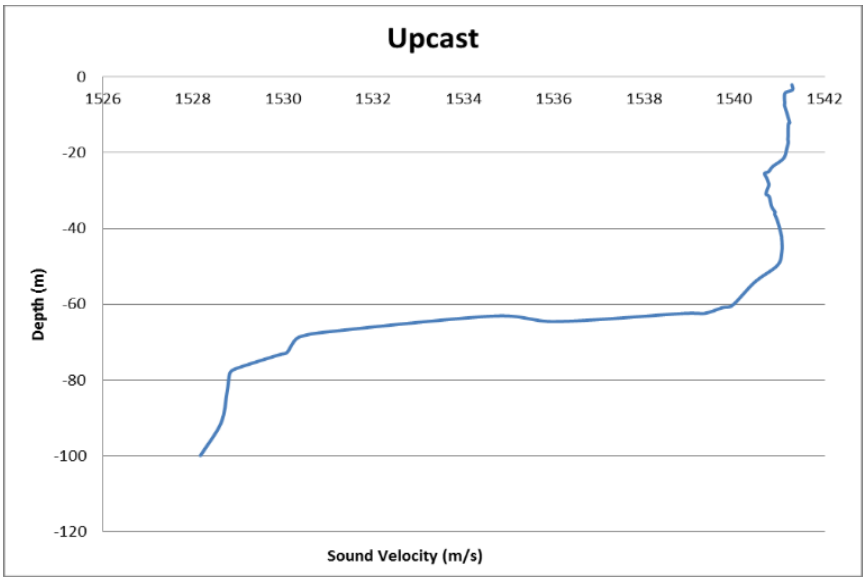

Fig. 20 -The sound velocity during upcast at Lat: 06° 11′ 56.93″ N, Long: 098° 42′ 21.36″ E

Regarding the usage of those sound velocity profile in the maritime navigation and also the warfare application system, it is important to identify and make sure that the accuracy of the sound velocity. It is important to have an accurate reading of sound velocity especially when the travel time has to be converted to a distance and depth. The need of accuracy is seen in fathometry which is the method used to determine the seawater velocity and also in fire control, where the accurate range is needed from the sonar data to launch a missile such as a torpedo. As the sonar system relies on the sound velocity profile, where it must be calibrated before it is being used by referring to sound velocity profile. It will give a big impact to the user if the data is not accurate and will cause accidents, fire control, and the missile operation also cannot comply with the effective target range.

Other than that, another application that requires accuracy is in the missile impact location by SOFAR triangulation, where the time travel of the sound velocity travelling in the Deep Sound Channel is then converted to a distance, where it serves to locate the point of impact. Without an accurate reading of the sound velocity will reduce the ability of the missile to reach the right target. The accuracy of the sound velocity can be proved by the calculation of range where the sound velocity travels down into certain depth. The range of the sound velocity is affected by the sound velocity at a certain depth and its time delay during the travelling time [3]. The calculation for range using the formula of:

$$R = \frac{CT}{2} \tag{2}$$

where R is range of the depth, C is sound velocity of the water and T is the time delay of the sound velocity [9]. As an example, if values of sound velocity at location A is 1538m/s at 60 m below sea water level, the travel times needed is 0.078 second but in the different location which is location B, the speed of sound is 1501 m/s at the same depth which is 60m below sea water level the travel time is 0.08 second. Therefore, the range for location A is 59.98 m and for location B is 60.04 m. The percentage of error for location A and B is 0.1%.

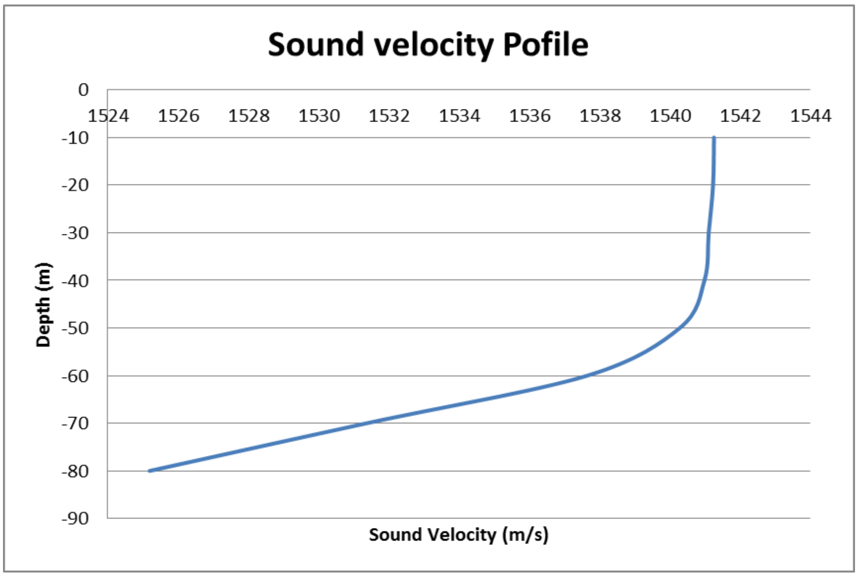

Fig. 21 - The average sound velocity profile for overall location at every 10 m depth

4. Conclusion

This project is mainly to investigate the sound velocity profile at 9 locations tested at Strait of Malacca where has been plotted and shown in the data and discussion section. Moreover, the other objectives are to identify the factors affecting the sound velocity in seawater and the plotting of the sound velocity profile. This objective of this research is achievable as the sound velocity profile for the 9 locations at Straits of Malacca is identified from the sound velocity probe after the survey done. Other than that, the factors that affect the sound velocity also have been determined which is temperature, salinity, and pressure. Furthermore, the profile for 9 locations at Strait of Malacca also has been plotted. Therefore, the sound velocity profile can be used as a reference for tactical warfare requirement and also for the navigation used for shipping and also submariners.

The accuracy of the sound velocity profile is important in terms of its usage for calibration of the echo sounder for single beam and multibeam system. The data also important in warfare to reach the target accurately. The profile comes out from this research may be less accurate and valid to be used for real maritime purposes. In order to get the accuracy, the sound velocity profile is suggested to be compared with the survey from the other hydrographic surveyor done before or with the aid of using the echo sounder to detect and compare the reading of the sound velocity at the 9 locations.

Other than that, the study about sound velocity profile is an interesting field as it is related to the hydrographic studies. The equipment used for the sound velocity survey will be more advanced in the future. Therefore, high technology equipment can be used to get more accuracy during the survey. Further studies on sound velocity profile are important to be done as it is very useful to maritime purposes especially for navigation in shipping and submariners also the warfare usage such to launch the missile and torpedo. Other than that, sound velocity profile also important for sea mapping. The recommended location to do the survey is at the South China Sea as it is widely used for passage especially for submarines because of its safe depth for navigation.

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