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Bathymetric Survey Using Singlebeam Echosounder for Calculation of Dredging Volume in Pertamina IV Cilacap Port Channel

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ABSTRACT

The TUKS 60 Cilacap Port area is facing significant challenges due to sedimentation that causes the approach channel to silt up, thereby disrupting navigation and ship operations. This study identifies the depth distribution, assesses the quality of the bathymetric survey, and calculates the volume of dredged material needed to maintain a channel depth of 8 meters below the chart datum. The method used is a bathymetric survey using the Odom Hidrotrac II Singlebeam Echosounder (SBES), geodetic data from CORS-based GPS, and tidal correction from Low Water Spring. (LWS). Data processing was carried out using Hypack 2015 software and the average end area method for volume calculation. Survey data were validated using the criteria from the International Hydrographic Organization (IHO) S-44 Edition 6.1.0 standard. (2020). The results show a depth ranging from -1.2 meters to 10 meters, with 95.8% meeting the exclusive and special order criteria. The volume of dredging required to reach the design depth is 159,991 m³. These findings support dredging planning while ensuring navigational safety and operational sustainability of the port, demonstrating the reliability of SBES technology, Hypack 2015, and compliance with IHO validation for the dredging plan.

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INTRODUCTION

The Pertamina TUKS Port (Terminal for Own Use) Area 60, managed by PT Pertamina Refinery Unit IV Cilacap, is a strategic facility to support the transportation of gas and chemicals via maritime transport. Various types of tankers are operated to maintain the sustainability of energy and other important material distribution to various regions in Indonesia. As one of Pertamina's ports with nationally significant activities, optimal port management, including maintaining the depth of the shipping lane, is a primary necessity to ensure navigation safety and operational continuity.

However, this port faces significant challenges due to sedimentation occurring in the Donan River. Sediment deposits in the waters of Cilacap, particularly around the mouth of the Donan River, directly affect shipping routes (Froditus et al., 2019). This condition can hinder ship access, slow down navigation, and increase the risk of accidents and ship damage. The port's location in the river area makes it vulnerable to disturbances caused by natural siltation at the river mouth (Catherine et al., 2021).

Excessive sedimentation affects the depth of the channel, which is crucial for ensuring the smoothness and safety of ship traffic at Pertamina Cilacap Port. This sedimentation requires serious handling, as it not only increases operational risks but also has the potential to negatively impact the environment if not managed properly. Maintaining the depth of river estuaries through dredging is an essential step to ensure the smoothness and safety of navigation activities (Schoeneich et al., 2023). Therefore, optimizing the depth of port channels and basins is crucial for maintaining safety, reducing energy consumption, and minimizing environmental impact, while also ensuring navigation safety (Paulauskas et al., 2023).

Maintaining the depth of navigation channels through dredging is the primary solution in addressing sedimentation. Dredging is the process of removing sediment from its natural deposit condition that hinders navigation and for port maintenance (Bianchini et al., 2019). In order for dredging to be carried out efficiently, a bathymetric survey is necessary to provide detailed data on the depth and characteristics of the riverbed. Bathymetry, as explained (Poerbondono & Djunasjah, 2005), is a process that includes detailed mapping of the waterbed, starting from measurement to data visualization. This information is important for the planning and execution of effective dredging. Bathymetric surveys using an echosounder can accurately calculate sedimentation volumes for dredging planning (Abidah et al., 2023). With accurate bathymetric data, port channel management can reduce operational risks and minimize environmental impact.

This study aims to identify and analyze the bathymetric conditions in the approach channel to the Pertamina TUKS Port Area 60 Cilacap dock using singlebeam echosounder technology (SBES). This research also validates the survey results based on the International Hydrographic Organization (IHO) S-44 Edition 6.1.0 (2020) standards and calculates the dredged material volume using Hypack software. The expected results can support dredging optimization and enhance the safety and efficiency of port operations with accurate data on dredging volume requirements.

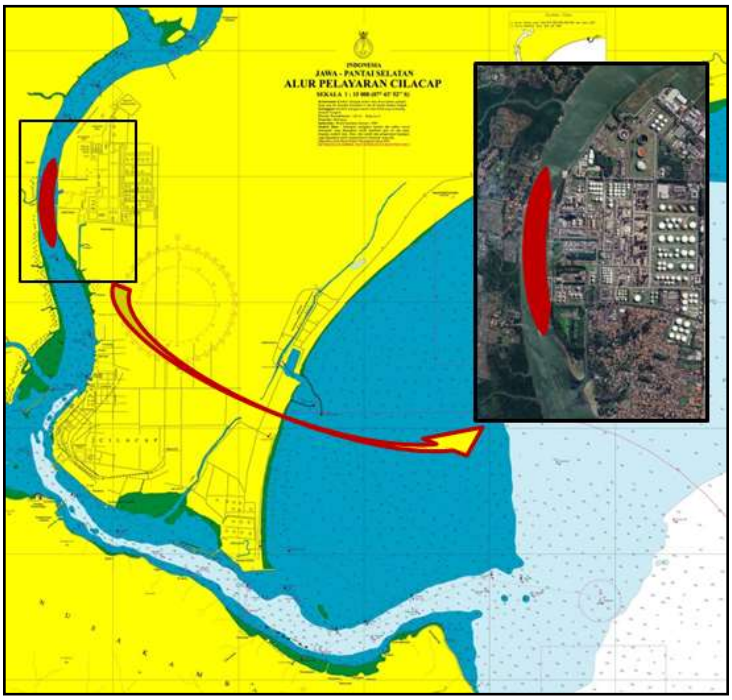

Figure 1. Research Location (Source: Indonesian Nautical Chart 108, Google Earth).

THEORETICAL REVIEW

Bathymetry

Bathymetry is a part of hydrography that focuses on measuring the depth of water bodies to ensure navigation safety and prevent hazards (Specht et al., 2021). In this study, a bathymetric survey was conducted using the Singlebeam Echosounder (SBES) Odom Hidrotrac II. Underwater acoustic technology such as the SBES and Multibeam Echosounder (MBES) systems is crucial for bathymetric mapping in Indonesian waters because they can collect data in real-time and have a high level of accuracy (Lubis et al., 2019). SBES Odom Hidrotrac II is combined with a positioning system using Differential Global Positioning System (DGPS) with GPS 5700 and an Automatic Data Logging (ADL) device on the Hypack equipment. The survey was conducted with a distance between lines of 10 meters for the main line and 50 meters for the cross line, to ensure adequate data coverage according to the survey scale.

The processing of bathymetric data involves tidal correction to determine the actual depth and cleaning the data from noise that may affect the results (Ismail et al., 2023). The tidal correction is performed using Microsoft Excel software, followed by using Hypack 2015 software to adjust the depth figures against the Low Water Spring reference (LWS). Additionally, calibration of the echosounder equipment is performed before and after the survey using the barcheck technique for accurate depth readings. The calibration process is conducted at 1-meter intervals, starting from a depth of 1 meter up to 5 meters using the barcheck tool (steel plate).

To ensure the quality and accuracy of the data, quality control is performed through analysis that compares the depth data from the main lane with the cross lane that overlaps (Poerbondono & Djunasjah, 2005). This analysis is conducted using the Cross Check Statistics feature in the Hypack 2015 software, which allows for the comparison of depth data from two intersecting lanes. The obtained data is then further analyzed through the calculation of Total Vertical Uncertainty (TVU) using Microsoft Excel.

The calculation of TVU refers to the standards set by IHO S-44 edition 6.1.0 (2022), with a confidence level of 95%. This standard integrates the concept of Total Propagated Uncertainty (TPU), which includes two main components, namely Total Horizontal Uncertainty (THU) and TVU. This value is understood as an uncertainty interval of ± the specified value, reflecting the accuracy level of the survey data.

According to S-44 edition 6.1.0, data accuracy is measured based on two components, depth-independent uncertainty (a) and depth-dependent uncertainty (b). The maximum TVU equation is as follows:

$$\boldsymbol{TVU_{max}}\,(\boldsymbol{d}) = \sqrt{a^2 + (b \times d)^2} \text{ .... (1)}$$

Were:

a = Coefficient representing uncertainty that is independent of depth.
b = Coefficient representing uncertainty that is dependent on depth.
d = Depth.

S-44 edition 6.1.0 establishes several orders of hydrographic surveys based on accuracy levels, namely Exclusive Order, Special Order, 1a, 1b, and 2. Each order has different criteria for maximum Vertical Uncertainty (TVU), as shown in Table 1.

Table 1. Criteria for Vertical Accuracy Criteria in Hydrographic Surveys.

Order	Maximum TVU (95% CL)	Coefficient
Exclusive	a = 0.15, b = 0.0075	Highest accuracy level for critical areas such as shipping lanes.
Special	a = 0.25, b = 0.0075	For areas with high accuracy requirements such as docks.
1a	a = 0.50, b = 0.013	General navigation areas with moderate risk.
1b	a = 0.50, b = 0.013	Offshore areas with low risk.
2	a = 1.00, b = 0.023	Deep waters where seabed details are less significant.

Source: IHO S-44 Edition 6.1.0 (2020).

Validation is carried out by comparing the difference in the obtained depth data against the maximum TVU value adjusted to the survey order criteria. If the difference in depth data is smaller than the maximum TVU value, then the data is declared to meet the criteria for that order. Conversely, if the difference in depth data is greater than the maximum TVU value, then the data does not meet the criteria. This process aims to ensure that the bathymetric data meets the minimum standards for hydrographic surveys as set by S-44 edition 6.1.0 (2020).

Mapping Control Points

Mapping control points are stable geodetic reference points used to determine the position and elevation of other points in mapping. The reference points used are a set of stable points and control points that are interconnected through measurements of differences in direction, distance, or elevation to form a geodetic network (Matsuoka et al., 2020). Determination of mapping control point coordinates through GPS surveys using the static positioning method (Julianto et al., 2018). The process of determining the coordinates of points within a network in a GPS survey consists of three stages: data processing from each baseline in the network, network adjustment involving all baselines to determine the coordinates of points within the network, and transformation of those point coordinates from the WGS-84 datum to the datum used by the user (Poerbondono & Djunasjah, 2005).

The level of accuracy of the horizontal position of control points is calculated based on THU, which is defined in the IHO S-44 standard edition 6.1.0. (2020). The maximum THU at a 95% confidence level for each survey order is shown in Table 2.

Table 2. Criteria for Horizontal Accuracy in Hydrographic Surveys.

Order	**Exclusive**	**Special**	**1a**	**1b**	**2**
Max allowed at 95% CL	1 m	2 m	5m+5%(d)	5 m+5%(d)	5m+10%(d)

Source: IHO S-44 Edition 6.1.0 (2020).

In this study, to determine the coordinates of control points, a geodetic observation survey using GPS was conducted with two reference points, the Continuously Operating Reference Station (CORS) Pangandaran (CPGN) and CORS Majenang (CMJG), managed by the Geospatial Information Agency (BIG). The observation data were processed using Trimble Business Center (TBC) version 5.0 software to obtain a fixed baseline, followed by network adjustment to ensure the accuracy of the control point coordinates. Figure 2 shows the baseline configuration connecting control points with two CORS reference stations, which are used to determine geodetic coordinates with precision.

According to (BSN, 2002) regarding the National Horizontal Control Network, the network class of a mapping control point is determined based on the semi-major axis of each relative error ellipse (distance between points) with a 95% confidence level. The determination of the network class is conducted based on statistical analysis using the least squares adjustment method as a constrained minimal adjustment. The network is considered to meet certain standards if the results of the constrained adjustment show that the errors are within the tolerance limits. This result is to ensure that the control points used meet the accuracy standards required to support further analysis. In Table 3, the empirical factor value (c) is displayed, which indicates the survey precision level in the equation adjusted to the selected class. The long formula is:

$$r = c \times (d + 0.2) \dots\dots\dots\dots\dots \quad (2)$$

Where:
r = maximum allowed axis length (mm).
c = Empirical factor that describes the survey precision level.
d = Distance between points (Km).

Table 3. Class of Measurement for the National Horizontal Control Network (JKHN).

Kelas	c (ppm)	Aplikasi Tipikal	Jarak	c (cm)
3A	0,01	Permanent (continuous) GPS network	1.000	1
2A	0,1	National scale geodetic survey	500	3
A	1	Regional scale geodetic survey	100	7.5
B	10	Local scale geodetic survey	10	15
C	30	Geodetic survey for intersections	2	30
D	50	Mapping survey	-	50

Source: SNI 19-6724-2002, National Horizontal Control Network.

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Figure 2. Base Line Control Point Mapping (Source: Google Earth).

Tidal Observations

During the bathymetric survey, tidal observations were conducted to correct the measured depth (Khomsin & Pratomo, 2020). In this study, tidal observations during the bathymetric survey were conducted using the automated Tide Master measuring instrument with a 5-minute observation interval. The tidal observations during the survey period were carried out at the Kutawaru Cilacap pier and were tied to the mapping reference point BM 01 Pertamina. The data obtained is used to correct the sounding results based on the Tide Level obtained during the tidal observation (Kusuma et al., 2021). This correction aims to ensure that the depth results measured during the bathymetric survey reflect the actual depth below Mean Sea Level (MSL).

The correction process is carried out using two main formulas:

1. Tide Reduction Formula:

$$\boldsymbol{r_t} = TWL_t - (MSL + Z_0) \ldots\ldots\ldots\ldots\ldots (3)$$

Where:

r_t : The amount of reduction applied to the depth measurement at time t.
TWL_t : True Water Level/ the measured sea surface position at time t.
MSL : Mean Sea Level.
Z_0 : Depth of the water surface below MSL.

2. Actual Depth Formula:

$$\boldsymbol{D} = D_T - r_t \ldots\ldots\ldots\ldots\ldots (4)$$

Where:

$\boldsymbol{D}$: Actual depth.
D_T : Corrected depth (measured using a transducer).
r_t : Reduction of tidal sea water that has been calculated with the formula (3).

This correction ensures that all reported depths are consistent with the MSL reference and take into account changes in sea surface height at the time the survey was conducted. Thus, the obtained data is more accurate and can be used for dredging planning or further bathymetric analysis.

Dredging volume

The dredging volume is calculated using the average end area method, which is applied in the Cross Section and Volumes program in Hypack 2015 software. This method is used to calculate the volume of material between two cross-sections by taking the average area of the two cross-sections and then multiplying it by the distance between the cross-sections to obtain the volume of material to be dredged (Hypack, 2017). The volume calculation equation in the average end area method is as follows:

$$\boldsymbol{V} = L\,x\,\frac{(A_1 + A_2)}{2} \ldots\ldots\ldots\ldots\ldots (5)$$

Where:
$\boldsymbol{V}$ = Volume between cross-sections.
A_1 and A_2 = The areas of two adjacent cross-sections.
L = The distance between two cross-sections.

In this study, the dredging volume is calculated up to a depth of 8 meters below the chart datum. The process of calculating dredging volume using Hypack 2015 software begins with preparing three main types of data: surface bathymetry data, channel design, and cross section. Surface bathymetry data (xyz) provides actual depth information from the survey results, while channel design (chn), which is a channel design template, is used to define the shape and target depth of the dredging. Cross section (lnw) is the definition of a cross-section that divides the dredging area into segments, allowing for volume analysis per section. These three data sets are input into software to define the channel geometry and the material to be dredged. A design template is applied to the bathymetric data to determine the areas that require dredging, by comparing the actual depth against the design depth.

The volume of material is calculated by interpolating the area between two adjacent cross-sections, using the average cross-sectional area formula. The distance between the cross-sections is used as a multiplier to generate the volume of material between the cross-sections. Calculations are performed up to a depth of 8 meters below chart datum, ensuring that the data has been corrected using the Low Water Spring reference (LWS).

METHODOLOGY

This research uses the technical survey method, which involves the collection of primary data through field surveys conducted in the approach channel of Pertamina Port TUKS Area 60 Cilacap. The technical survey is an approach that relies on the collection of primary data through direct measurements in the field, with the aim of obtaining accurate and specific data according to certain technical needs (Phelan, 1999). The data collected includes bathymetric surveys using a singlebeam echosounder, geodetic position measurements using GPS, and tidal observations. This method aims to ensure the accuracy and relevance of the data required for dredging volume calculations.

RESULTS AND DISCUSSION

Bathymetry

The mooring area with a residential area of ± 15.85 Ha. The results of the bathymetric survey show depths varying between -1.2 meters and 10 meters, after being adjusted with tidal corrections using the Low Water Spring reference (LWS). This correction process ensures that the reported depth is an accurate representation of the actual conditions below Mean Sea Level (MSL), making it suitable as a basis for dredging planning. Figure 3 shows the results of the bathymetric mapping visualized in the form of a Digital Elevation Model (DEM).

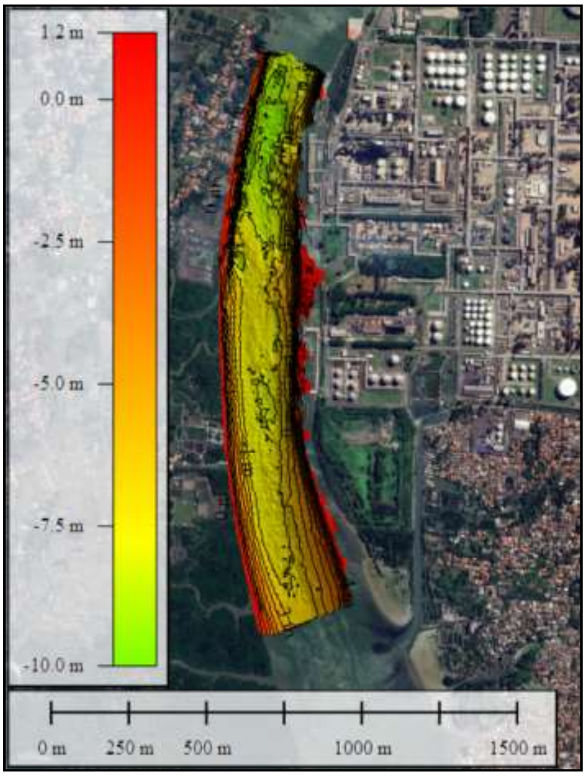

Figure 3. Bathymetric Measurement Results.

Quality control of mooring data is a step that must be carried out to ensure the accuracy and validity of the data produced in accordance with the established standards (Nugraha et al., 2022). Table 4 shows the results of the classification of bathymetric survey data quality based on the minimum standards for hydrographic surveys as regulated in IHO S-44 Edition 6.1.0. (2020). Based on the data processing results, 90.7% of the total data meets the exclusive order criteria, 5.1% meets the special order criteria, 4.3% meets the 1a/1b order criteria, and no data falls into order 2.

Table 4. Classification and Quality of Bathymetric Data Based on IHO S-44 Edition 6.1.0

Order	Percentage (%)	Data Quality
Exclusive	90.7	Highest accuracy level, suitable for critical areas such as shipping lanes and docks, with a very small maximum vertical uncertainty (TVU).
Special	5.1	High accuracy, used for general shipping areas or waters with a high risk level.
1a/1b	4.3	Medium accuracy, used for open waters or areas where the accuracy of seabed details is not critical.
2	0	Lower precision level, usually used for deep waters or areas where seabed details are less significant.

Source: Processing Results.

Figure 4 below shows the distribution of bathymetric survey data quality.

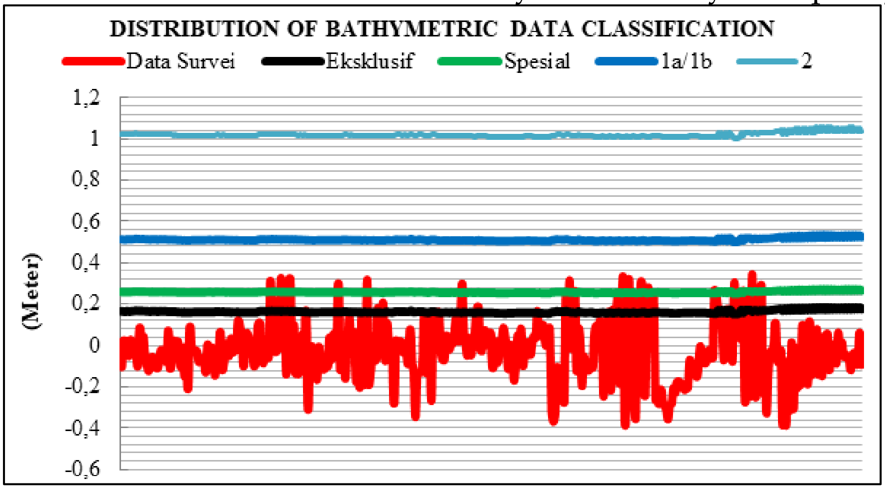

Figure 4. Graph of Bathymetric Data Classification Distribution

This high-quality data ensures that dredging planning can be carried out efficiently, with a more accurate estimation of dredged material volume. With the majority of the data quality falling into the highest category (95.8%), meeting the criteria for exclusive and special orders, the risk of errors in volume calculation, technical planning, and operations such as dredging or navigation can be minimized. These results reflect the survey's compliance with the minimum quality standards for hydrographic surveys as outlined in IHO Publication S-44 Edition 6.1.0 (2020), thereby supporting efficient and data-driven operational planning.

Mapping Control Point

Geodetic surveys indicate that BM. 01 Pertamina is located at 7° 41' 51.92029" S - 108° 59' 25.93066" E, with an ellipsoidal height of 24.028 meters. The processing of baseline data and network adjustment resulted in an ellipsoidal error value of 0.011 meters, which still meets the IHO S-44 Edition 6 standards (2020).

All network adjustment results passed the chi-square test, with a reference factor value of 1.0 and a degree of freedom of 4, and a confidence level of 95%. The ellipsoid error values for each baseline are presented in Table 5, which shows that all mapping control points meet the established standards.

Table 5. Baseline Processing Results

Observation	From	To	Solution Type	H. Prec. (m)	V. Prec. (m)	Geodetic Az.	Ellipsoid Dist. (m)	ΔHeight (m)
CMJG - BM. 01 (B1)	CMJG	BM. 01	Fixed	0.029	0.095	148°19'51"	51631.044	-26.246
CMJG - CPGN (B2)	CMJG	CPGN	Fixed	0.012	0.079	214°18'42"	45717.712	79.147
CPGN - BM. 01 (B3)	CPGN	BM. 01	Fixed	0.029	0.095	96°41'53"	53237.569	-105.421

Source: Baseline Processing Report.

After conducting the baseline analysis and network adjustment on the observed points, the ellipsoidal error value at BM. 01 Pertamina is 0.011 meters as shown in Table 6. Based on the processing results, the ellipsoidal error value at BM. 01 PT with reference points CPGN and CMJG still meets the established standards.

Table 6. Ellipsoid Error Values of Mapping Control Points.

Point ID	***Semi-major Axis* (m)**	***Semi-minor axis* (m)**	***Azimuth***
BM. 01	0.012	0.011	169°

Source: Network Adjustment Report Processing Results.

Geodetic network measurements with reference to the CORS Pangandaran (CPGN) and CORS Majenang (CMJG) stations show that the semi-major axis values are below the maximum limit for class A, which are 51.8310 mm and 53.4376 mm. The semi-major axis value for the CMJG - BM. 01 Pertamina baseline is 9.818 mm, while for the CPGN - BM. 01 Pertamina baseline it is 8.912 mm, as shown in Table 7.

Table 7. Class of Measurement for the National Horizontal Control Network (JKHN).

Baseline		**Distance (d)**	**Horizontal Precision**		**Ellips Semi Major Axis (r)**		
From	**To**	**(km)**	**Ratio**	**PPM**	**Allowable Class**	**Calculated Class**	**Result**
CMJG	BM. 01	51.631049	1 : 5258828	0.19016	51.8310	9.818	Complies
CPGN	BM. 01	53.237596	1 : 5973553	0.16740	53.4376	8.912	Complies

Source: Processing Results.

Thus, all positioning equipment used in the survey activities has a high level of horizontal accuracy with a THU of less than 2 meters, which can minimize the risk of positional errors. This is very important to ensure the accuracy of depth data used in the dredging planning at the approach channel of Pertamina IV Cilacap Port.

Tide Observation

The observation results indicate that the Low Water Spring (LWS) value is at 1.66 m above the tidepole zero. This data is used in the process of correcting the subsidence of the survey depth results, so that the measured depth can be adjusted to the Mean Sea Level reference (MSL). The tide graph during the survey period is shown in Figure 5.

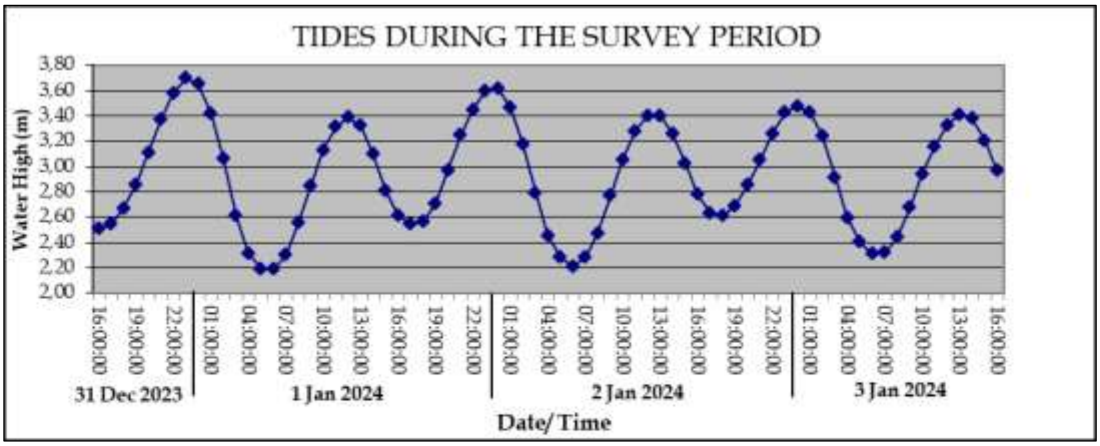

Figure 5. Tidal Graph for the Survey Period.

The binding of tidal observation data was carried out using the leveling process, which connects the tidal observations with the mapping reference point BM 01 Pertamina. The leveling results show that the height of BM 01 Pertamina relative to the zero tidepole is 4.74 meters. The height of BM 01 Pertamina relative to the LWS is 3.08 meters, and the height of the LWS relative to the zero tidepole is 1.66 meters. The leveling results, between the tidepole and the mapping reference point BM 01 Pertamina, are presented in Figure 6 to provide a visual representation of the vertical relationship between the reference point and the water surface.

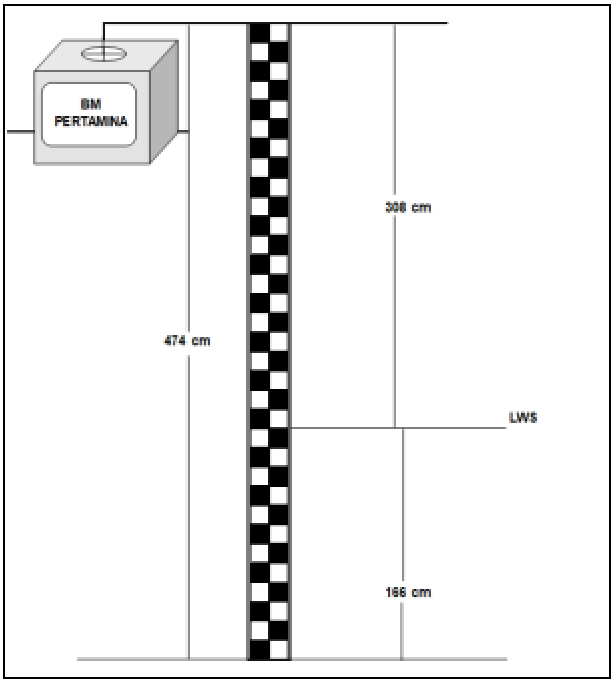

Figure 6. Position of BM Relative to Tidepole.

The use of the tidal reduction formula rt and the actual depth D plays an important role in ensuring the accuracy of the obtained depth data. By applying tidal corrections based on the measured TWL, the reported depth becomes a more accurate representation of the actual conditions below MSL. For example, if the depth measured at time t is dT = 10 meters, and the tidal reduction calculation shows = 0.5 meters, then the actual depth D produced is:

$$\boldsymbol{D} = 10\,m - 0.5\,m = 0.95\,m \qquad (6)$$

These results indicate that the reported depths have taken into account sea level changes and provide more reliable information for dredging and navigation planning.

By applying the correct tidal corrections, in accordance with the IHO S-44 guidelines, the bathymetric survey results show accurate and reliable depths. This is important for efficient dredging planning, where the volume of material to be dredged is calculated based on the corrected depth data. Accurate tidal observations ensure that the dredging volume calculations are not affected by uncertainties related to sea surface variations.

Dredging Volume Calculation

The dredging volume calculation using Hypack 2015 software with the average end area method resulted in a total dredging volume of 159,991 m³ to achieve a design depth of 8 meters below chart datum. The volume consists of 133,723.8 m³ for the main area and 26,267.2 m³ for the channel slope area. In Figure 7, the integration of surface data, channel design, and cross section is shown in the Hypack 2015 software to determine the volume between adjacent cross-sections, resulting in the accumulation of dredging volume.

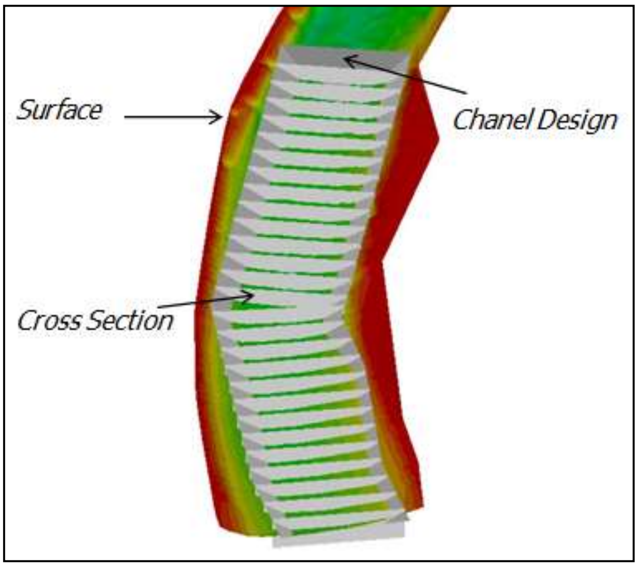

Figure 7. Integration of Surface, Channel Design, and Cross Section.

The volume calculation results show a varying distribution of material in each section. The largest dredging volume was recorded in section 0+00 to 00+50, with a value of 14,298.1 m³, indicating that this area has a greater accumulation of material compared to other areas. Conversely, the smallest dredging volume was in section 12+00 to 12+50, with a value of 1,342.5 m³, indicating that this area has little material to be dredged. The volume accumulation in section 0+00 to 05+00 reached 104,913.9 m³, or about 65.6% of the total dredging volume. This indicates that most of the material that needs to be dredged is concentrated in the initial area of the segment. Here are the results of the area and volume for each segment as shown in Table 8.

Table 8. Volume Results (m^3) in Hypack 2015.

Section	Distance (m)	Volume (m^3)	Accumulation (m^3)
00+00 to 00+50	50	14,298.1	14,298.1
00+50 to 01+00	50	12,578.6	26,876.7
01+00 to 01+50	50	10,997.1	37,873.8
01+50 to 02+00	50	10,755.2	48,629.0
02+00 to 02+50	50	10,935.7	59,564.7
02+50 to 03+00	50	10,631.2	70,195.9
03+00 to 03+50	50	10,078.3	80,274.2
03+50 to 04+00	50	9,774.0	90,048.2
04+00 to 04+50	50	8,568.9	98,617.1
04+50 to 05+00	50	6,296.8	104,913.9
05+00 to 05+50	50	4,119.2	109,033.1
05+50 to 06+00	50	2,882.9	111,916.0
06+00 to 06+50	50	2,616.2	114,532.2
06+50 to 07+00	50	1,596.9	116,129.1
07+00 to 07+50	50	1,636.4	117,765.5
07+50 to 08+00	50	2,007.2	119,772.7
08+00 to 08+50	50	2,923.3	122,696.0
08+50 to 09+00	50	2,204.8	124,900.8
09+00 to 09+50	50	3,196.1	128,096.9
09+50 to 10+00	50	4,415.5	132,512.4
10+00 to 10+50	50	6,686.4	139,198.8
10+50 to 11+00	50	7,477.2	146,676.0
11+00 to 11+50	50	5,970.3	152,646.3
11+50 to 12+00	50	3,359.3	156,005.6
12+00 to 12+50	50	1,342.5	157,348.1
12+50 to 13+00	50	2,642.8	159,991.0

Source: Processing Results.

With the identified volume, it provides a strong basis for determining the dredging plan. This approach ensures that dredging in the approach channel of

Pertamina IV Cilacap Port can be carried out efficiently, minimizing operational time and costs, while also meeting the design depth target of 8 meters below chart datum.

CONCLUSIONS AND RECOMMENDATIONS

The results of the geodetic survey that meet the IHO S-44 and SNI 19-6724-2002 standards indicate that the mapping control points used in the bathymetric survey are accurate and suitable for regional applications. This ensures that the collected bathymetric data can be relied upon for dredging planning and port operations.

The varying depths in the survey area indicate the need for dredging in several areas to achieve a channel design with a depth of 8 meters below chart datum. The calibration and quality control processes carried out ensure that the generated data meets high-quality standards, which is important for port management.

Careful tidal observations and leveling measurements ensure that the tidal corrections applied to the bathymetric data are accurate. This is important to produce an accurate depth profile for dredging volume calculations.

The dredging volume calculation using Hypack 2015 shows that approximately 159,991 m^3 of material needs to be dredged to reach the desired depth. These results align with expectations and demonstrate that the method used is effective in providing an accurate estimation of dredging volume. This research makes a significant contribution by combining SBES technology and Hypack software, validated using the latest IHO S-44 Edition 6.1.0 standards, to produce high-quality bathymetric data for dredging planning.

FURTHER STUDY

This research has successfully identified the bathymetric conditions and dredging volume in the approach channel of Pertamina TUKS Port Area 60 Cilacap. However, there are several limitations that need to be considered. One of the limitations is the width between cross-sections, which, although it produces accurate data, is less optimal for areas with high underwater complexity. We recommend further research to reduce the distance between cross-sections, especially in complex areas.

Further studies are also recommended to integrate sedimentation models capable of dynamically predicting changes in the depth of navigation channels. Thus, the prediction of dredging needs and periods can be planned more effectively, supporting the efficiency of time and operational costs. In addition, it is important to assess the impact of management on the local environment, including ecosystem analysis, so that port management can be carried out more sustainably. This approach is expected to improve the efficiency of port operations, navigation safety, and environmental management in the future.

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