Hydrographic Survey in Basic Design Stage of Immersed Tunnel Planning for the New Capital City of Indonesia

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Keywords : Hydrographic Survey, Bathymetric, Tidal Survey, Mean Sea Level, Immersed Tunnel

SUMMARY

Indonesia, one of the world's biggest economic countries, is currently developing a new capital city to replace the current capital of Indonesia, Jakarta. The Immersed Tunnel being one of the advanced infrastructure technologies is applied in the development of the new Capital City. The Immersed Tunnel is an underwater tunnel that span 750 meters across the Sepaku River. This tunnel plays role for the road network infrastructure in the city. The design of Immersed Tunnel requires a large scale of topographic data with a high level of detail. To provide highly accurate planning data, Hutama Karya conducted a hydrographic survey using Multi-Beam and Single Beam Echosounder to obtain the underwater topographic in the location of Immersed Tunnel. The MBES Survey specification is refer to Order 1B with 100% bathymetric coverage. The SBES Survey is used to complement the MBES specifically in the branch with qualification of Order 1B. Furthermore, to complete the land topography data on the shore area, Hutama Karya used LiDAR Data from an airborne survey sourced from the Geospatial Information Agency with a scale of 1:1000.

The bathymetric survey controlled through Bench Mark (BM) coordinate point located in a jetty at the survey location. Horizontal BM coordinate is measured by observing GNSS for 6 hours that simultaneously record the data with others GNSS CORS Base (CPEN and CBAL CORS) from Geospatial Information Agency. All the three data are adjusted with network adjustment method to provide the accurate horizontal coordinate. Vertical elevation of BM coordinate is defined from tidal survey for 30 days, which resulted in mean sea level (MSL) and value of Chart Datum (CD) as the reference for bathymetric data. The vertical elevation of BM from tidal survey is 2.033 m. The vertical elevation of BM value also verified by measuring the BM elevation using Total Station referred to the nearest control point network from Geospatial Information Agency. The result of the vertical elevation BM value from Total Station is 2.056 m, that has 2.6 cm deviation from vertical elevation from MSL. The tidal survey in BM is calculated using British Admiralty. The output from this calculation is the harmonic constituents to analyse the Formzahl value, that resulted in 0.36. According to the Formzahl value, the type of tidal in the location is mixed tide of prevailing diurnal.

Furthermore, the result of MBES Data according to the depth TVU is classified to special order with 95% level of confidence. The process of merging LiDAR data with Bathymetri is carried out by referring to the same BM elevation value. Afterwards, adjust the LiDAR and Bathymetric data using a correlated BM point coordinate to obtain a connection between land and water topography. The output of this activity is to provide bathymetric chart, digital terrain model, and contour with the interval of 1m from bathymetric and lidar survey for basic design stage for immersed tunnel.

1 INTRODUCTION

1.1 Background

Indonesia, one of the world's biggest economic countries, is currently developing a new capital city to replace the current capital of Indonesia, DKI Jakarta. The new capital city of Indonesia, located in Borneo Island, in the province of East Borneo and named 'Nusantara'. The development for Nusantara required many new buildings and infrastructures to support the mobility and government system. Therefore, Hutama Karya as the state owned enterprise company play the role to design and build the road infrastructure in the new capital city of Indonesia using the advanced technology infrastructure. The new technology that implemented for road infrastructure in Nusantara is the Immersed Tunnel. This Immersed Tunnel is an underwater tunnel connecting the Highway from Balikpapan (segment 1,2, 3a, 3b) to the new capital city Nusantara.

Figure 1. Road connection between Balikpapan and Nusantara

The Immersed Tunnel is part of segment 4b that linked two pathway which the entrance location is placed in each shore of the route. Immersed tunnel in Sepaku River has 1,050 meters span that crossing the river which consist of 7 tunnel elements. Therefore, the urgency of this project is define the elevation of the land near the ramps position, the elevation of the terrain which the Immersed Tunnel was designed to build and also to combine both of the data in same vertical datum.

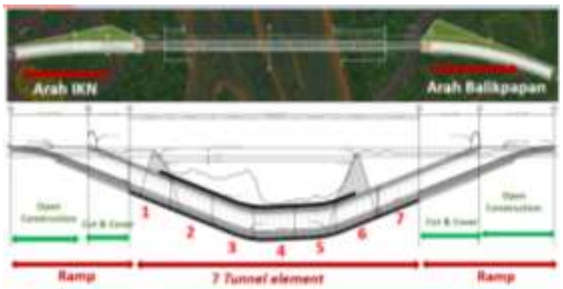

Figure 2. Plan View and Longitudinal Section of Sepaku Immersed Tunnel

The planning and design process of the tunnel need a highly accurate hydrographic data as the underwater topographic data. The design of Immersed Tunnel requires a large scale of topographic data, for scale 1:5000 with a high level of detail. To provide highly accurate planning data, Hutama Karya conducted a hydrographic survey using Multi-Beam and Single Beam Echosounder to obtain the underwater topographic in the location of Immersed Tunnel and complete the shore topographic data using LiDAR Airborne data from Indonesia Geospasial Information Agency .

1.2 Objectives

The objectives of this research are :

1. Conducting the hydrographic and oceanographic survey for the Immersed Tunnel.
2. Analysing and evaluating the result of the survey to fulfil the requirement Basic Design Stage for Immersed Tunnel.
3. Combining the topographic data for Immersed Tunnel design using LiDAR Airborne and Hydrographic Data.

1.3 Benefit of Research

The benefits from this research are :

1. Obtain the large-scale hydrographic data for Immersed Tunnel Design and Planning.
2. Obtain the information of accuracy and class level of the data.
3. Obtained the complete topographic data for underwater data and in the shore area.

2 METHODOLOGY

2.1 Data Source

The data used in the study are :

1. GNSS CORS located in Balikpapan, East Kalimantan, Indonesia.
2. Existing Bench Mark Point Located in Sepaku and Penajam Paser Utara Area.
3. Trace of the Road Planning.
4. Topographic Data in Balikpapan area from National Geospatial Information Agency.

2.2 Tools

The tools that needed from the study are :

1. Geodetic GPS
2. Multi beam Echosounder
3. Single beam Echosounder
4. Waterpass Level Instrument
5. Levelling Staff
6. Tide Master and Tidal Staff
7. LiDAR Data Processing Software
8. Hydrographic Software for Data Acquisition and Processing

2.3 Project Locations

The location of the study located in Sepaku River, Penajam Paser Utara District, Balikpapan City, East Kalimantan, Indonesia.

Figure 3. Area of Survey

2.4 Workflow

Figure 4. Workflow Diagram

2.5 Methodology

2.5.1 Identify the spatial data in the survey location

The preliminary survey is held by collecting the spatial information regarding the survey area. Data and information are obtained from National Geospatial Information Agency of Indonesia ('BIG'), that provides the operational location of the Continuously Operating Reference Station for Global Navigation Satellite System (GNSS CORS) relatively closest to the survey area. The nearest GNSS CORS location from Sepaku River is CORS CPEN in Penajam Paser Utara and CORS CBAL in Balikpapan City. Both CORS are utilising as the horizontal reference during GNSS data processing with aim to acquire the highly accurate coordinate for Benchmark Point.

Figure 5. CORS correlation position

In order to attain the accurate result of the hydrographic survey, the Benchmark Point also established in the survey area. Benchmark point shaped in pillar located on the ground with 40cm of its is arise above the ground level, as shown in figure (2) below. The preliminary survey identifies one existing pillar in Jetty Port at PT Singlurus Pratama (SGP), and 2 others is located nearby PT SGP within the survey area. Here is the location of each Benchmark Pillar.

No	Benchmark Point	Locations
1	HP.64.09.046	Jetty PT Singlurus Pratama (SGP)
2	TB.01	Beaching Port PT Handaitolan (HBH)
3	TB.02	Ponton Port PT ITCI Kartika Utama (ITCIKU)


Figure 6. Benchmark Pillar HP.64.09.046 in PT SGP

Benchmark Pillar in PT SGP is utilising as main reference point for the survey; thus the pillar will be surveyed using GNSS Method to define the horizontal coordinate. For the vertical coordinate is obtained from the tidal survey which the elevation is referred to define the Z of the benchmark.

The existing topographic data in the Sepaku Area already existed from Airborne Light Detection and Ranging (Airborne LiDAR) survey for scale of 1:5.000. Airborne LiDAR or Airborne Laser Scanning (ALS) provides an alternative for high density and high accuracy three-dimensional terrain point data acquisition. LiDAR data is a major source of digital terrain information and have been used widely areas (Liu et al. 2008). Output from the LiDAR Survey are Digital Surface Model (DSM), Digital Terrain Model (DTM), Contour, 3D point cloud, and aerial imagery. The resolution for Aerial Imagery is 0,15 m. The 3D point cloud are also classified for ground and non-ground class that fulfil the quality standard for airborne survey and LE90 accuracy test for topographic map scale 1:5000.

2.5.2 <u>GNSS Data Survey and Processing</u>

The GNSS Data survey are obtained using static method to define the coordinate for BM HP.64.09.046, TB.01, and TB.02. The static mode allows reaching the highest precisions, despite the time involved for the survey and data processing could limit the applications

(Dardanelli et al. 2021). Based on the range of CORS CPEN and CBAL to each Benchmark Point, the longest baseline distance reaches up to 70,42 KM. According to IHO Publications C-13, for the GNSS data observations with the baseline length is more than 70 kilometres, the observation is held for 4 hours or more. The GNSS survey should met the National Standard of Indonesia ('SNI') for Horizontal Network Control which define the minimum specification of observation. GNSS Static method is using dual frequency GNSS with baseline configuration for network adjustment (Badan Standarisasi Nasional 2002). The minimum satellite during acquisition is 4, with the PDOP maximum is 5, and the elevation mask set as 15^{o}. Baseline network configuration for the GNSS static survey can be seen in the figure (3).

Figure 7. Baseline Configuration for GNSS Observation

Figure (7) above displayed the network configuration for CPEN – HP.64.09.046 –CBAL, CPEN – TB.01 – CBAL, CPEN – TB.02 – CBAL. Each Benchmark Coordinate will define by CORS CBAL and CORS CPEN.

GNSS data processing is using Trimble Business Centre Software with baseline processing to acquire the fix baseline and followed by network adjustment method. Baseline processing has the constraint to met the RMS maximum is 0,02 for GNSS dual frequency, ratio more than 1,5 and variance of the reference is less than 10.

2.5.3 Hydrographic Data Survey

Hydrographic survey separated in several stages, i.e. Survey Preparation, Calibration and Patch Test, Performance Test, Barcheck, Depth Correction and Data Processing, and followed by QA/QC Process (PUSHIDROSAL 2022). Survey area divided by two, the main area (area 1) is the main river with the river width around 800 – 1,2 KM which this area will be fully covered by Multi Beam Echosounder (MBES). The other area, which is categorised as branch of the river will be covered using Single Beam Echosounder (SBES).

The survey is qualified for Order 1B IHO Standard Publications Edition 5 year of 2008 for both MBES and SBES tools.

- Survey Preparation

  The survey preparation include preparation for SBES and MBES before survey. MBES and SBES required the sounding lane as the route line that will be followed along tracklines. The lane is defined into main lane and crossing lane. The main sounding lane in Sepaku river has the direction around 30^{o} and 210^{o}, and perpendicular to the coastline. The main sounding are fully coverage with the specification of the spacing between main lane is according to the maximum swath angle of MBES is 70^{0} x depth. Therefore, the spacing lane between main sounding lane is 56 meters. The crossing lane

is designed perpendicular to the main lane with space between crossing lane is 20x space for the main lane.
For the SBES, the sounding lane designed with scale 1:5000 with the lane direction is parallel to the coast river line with the spacing of sounding lane is 40m. The crossing lane is perpendicular to its main lane as the quality control of the data. The difference elevation between main lane and crossing lane shall be less than 0.3 meters. The setting parameter of backscatter is activated during the survey to gain the information for sediment analysis based on the intensity value.
The offset of the each sounding system and positioning is calculated based on the centre of gravity. The dimension and lever arm value are inputted to vessel configuration for the acquisition software. The offset configuration can be found in the figure below. Differs from MBES, the configuration of positioning antenna and transducer is located at the same segment and already build up in the relative positions of the Center of Gravity.

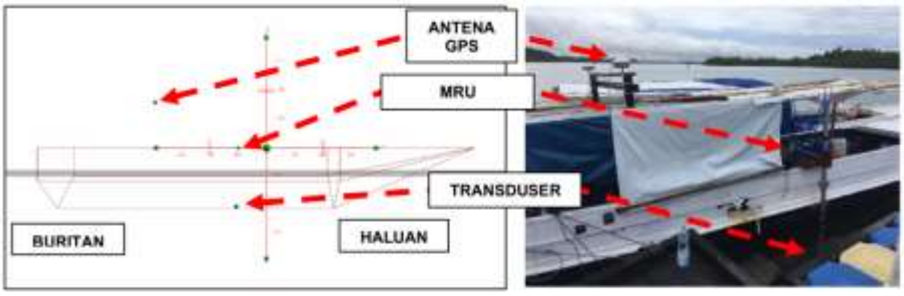

Figure 8. MBES Lever Arm Configuration

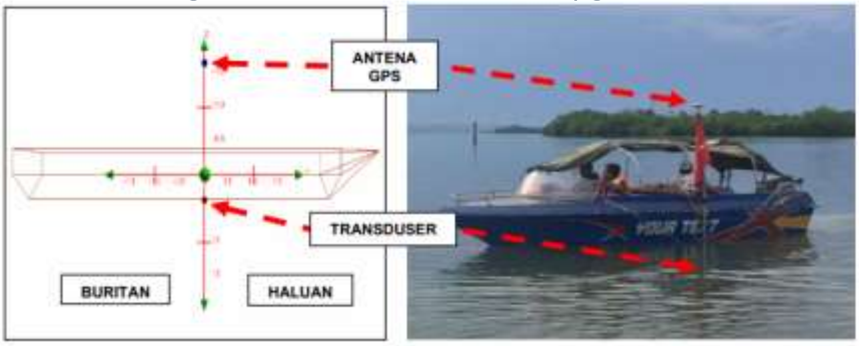

Figure 9. SBES Lever Arm Configuration

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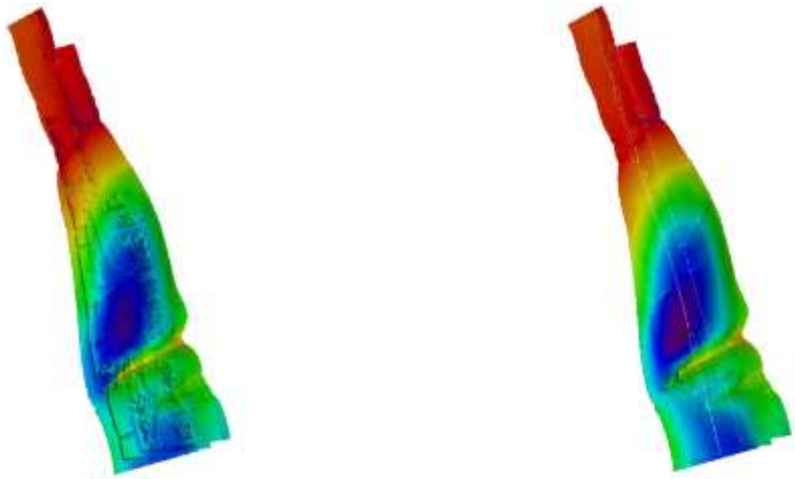
- MBES Calibration Patch Test
  Patch test will be held in the ocean floor condition relatively flat and in the relatively slope area. Patch test is one of the procedures which must be fulfilled by the hydrographers to assure IHO Order 1 horizontal and vertical accuracy (Yang et al. 2013). Patch test calibration in this stage is prior to the survey to minimize the effect of systematic errors that impacted in MBES data sounding (Le Deunf et al. 2020). The purpose is to calibrate the roll, pitch, yaw, and latency. Transducer mounting position calibration is carried out to obtain the corrected value between the position of the transducer to position that is considered correct and appropriate. Thus, the Digital Terrain Model (DTM) MBES data can overlap properly. Calibration latency is applied

to receive the time delay correction value positioning. Patch test activities are carried out in areas with a base the sea is relatively flat for roll calibration, and in areas with seafloor relative slope for pitch calibration (nod), yaw (deviation), and latency (time delay). Below is a DTM image of the ocean floor before and after calibrating the patch test value.



(10a) (10b)

Figure 10a and 10b. (10a) Seafloor DTM before Patchtest Callibration (10b) Seafloor DTM after Patchtest Callibration

Patch test calibration obtained each day of the survey. Environmental conditions also impacted the sounding system. The conditions that influence the system i.e. tide of the ocean and the sound velocity profile. In the survey, the SVP corrections are also required to complement the patch test data correction.

- Performance Test

  Verification of the performance of all the MBES system is held to acknowledge the limit of the transducer beam angles, based on analysis from Total Vertical Uncertainty (TVU) for each 1 degree of beam angle. Performance test is done in the relatively flat ocean floor. In the performance test, the bathymetry coverage is set to 250%, as of the bathymetry data in the nadir transducer could be used as the referenced data for all transducer beam angle.

Figure 11. Depth TVU Graph for each beam angle of MBES Transducer

Based on the graphical image, the width of the MBES swath between -70 to 68 degrees could reach the depth of TVU in order 1a/1b in case the survey area is relatively flat.

- Barcheck
  Barcheck only performed in SBES survey area to gain the information of the depth in the ocean survey that used to check the depth reading in the SBES survey.
- Depth Correction and Data Processing
  The depth correction is used to correct the depth data from Multibeam and Single Beam Echosounder based on tidal data survey in the primary tidal station in SGP. The data processing is using the patch test data calibration, tidal data correction, Sound Velocity Profiler, and clearance data from any blunder data. The output is bathymetric data format .xyz that already referred to the Chart Datum. The value for the depth correction could be shown in the table below.

CD	**Z_0**	**LAT**
241 cm	180 cm	61 cm

- QA/QC Topographic Data
  The quality control of the sounding data is calculated in the crossing lane of the bathymetry survey. The result of the Quality Control of Bathymetric shall meet the minimum standard of hydrographic survey orde 1A with the level of confidence 95%. Maximmum TVU was calculated by accounting for the fixed and variable vertical uncertainties associated with increasing depths (Costa, Battista, and Pittman 2009). Maximum TVU allowed shall fulfilled the equation below (IHO 2008):

$$TVU_{maks}\,(d) = \sqrt{a^2 + (b \times d)^2}$$

  For order 1A, the parametric of a = 0,5m, b = 0,013m, and d is the depth of the ocean as the reference. b x d represent the uncertainty of varies depth. The maximum THU that allowed in order 1A is 5 meter + 5% of the depth of the ocean floor.

2.5.4 <u>Oceanographic Data Survey</u>

Oceanographic data also acquired for this survey. The survey conducted are :

- Tidal Survey

Tidal analysis and prediction requires the understanding of astronomical and hydrodynamic aspect of the tide, which the relative periodic motions of earth, moon, and sun are determines the frequencies at which tidal energy is found. The contributions by the energy at tidal frequency is usually represented by a tidal harmonic constituent, for which there will be an amplitude and phase lag. The pairs of amplitude and phase lags are referred to as harmonic constants (Parker 2007). The tidal survey will propose to obtain the value of tidal constants. Tidal survey re conducted in the three locations of the tidal stations, i.e. Jetty Port at PT SGP, Beaching Port PT HBH, and Ponton Port PT ITCIKU. It will be measured for 29 days in PT SGP as the main tidal station. Otherwise, the PT HBH and PT ITCIKU is used as comparation station relatives to PT SGP, therefore the tidal on both locations only measured for 15 days. The result derived from these surveys are the defined Chart Datum value, Lowest Water Line, tidal constituents, tidal type, and tidal corrections in the survey area. Tidal data are calculated using British Admiralty.

- Levelling

Levelling is conducted to acquire the value for difference level between Benchmark point to the tidal palm. Levelling is measured twice for round with event amount of slag and measured independently to fulfil the levelling standard from National Standardisation Institution for Vertical Network Control (‘SNI JKV 19-6988-2004’). The result from levelling measurement is the vertical elevation related to the mean sea level. Elevation value that measured in Benchmark HP.64.09.046 will be used as vertical reference for Bathymetric data processing and data combination on hydrographic and existing LiDAR topographic data.

2.5.5 Hydrographic and Topographic Data Merge

Hydrographic and topographic data merge are processed to complement the hydrographic data with the existing topographic data from airborne lidar. The lidar data has point features that displayed the 3D elevation of each position on the shore, and the bathymetric data complementing in the river area. The process for data merge by utilising the same reference of elevation on the ground. The elevation that became the reference is the Benchmark HP.64.09.046 that already referred to Chart Datum. Ground point cloud from LiDAR is shifted to fit into the hydrographic data based on the elevation difference between Benchmark HP.64.09.046 and the LiDAR Point that located exactly in the coordinate position of Benchmark HP.64.09.046.

Definition	**Value (m)**
Mean Sea Level (S_0)	2.440
Benchmark Elevation to Zero Palm	4.443
Pillar Height	0.400
Benchmark Elevation on Ground	1.603
Ground LiDAR Elevation	2.277
Shifted Value (Height Difference Benchmark on Ground LiDAR and Ground Benchmark)	-0.674

The output from merging data process is 3D point elevation of LiDAR airborne and bathymetric point that already has the same elevation reference system which represented the actual topographic condition of the immersed tunnel area. These data are base to produce Digital Terrain Model and Contour to determine the elevation of the tunnel, the depth of the tunnel segment will be put under the water, also the point inlet and outlet of the tunnel.

3 OUTPUT AND RESULT

The output of the survey can be described below.

3.1 GNSS Data

The result of GNSS network adjustment for reference hydrographic data can be shown below.

Point Name	Latitude	Longitude	Height (m)	Height Error (m)	Descriptions
HP.64.09.046	1° 02' 24.7733" S	116° 44' 43.7352" T	55,853	0,017	
TB.01	0° 57' 38.7845" S	116° 48' 18.3835" T	56,894	0,049	
TB.02	1° 05' 35.4223" S	116° 43' 03.4385" T	57,671	0,045	
CPEN	1° 29' 49.6823" S	116° 27' 49.9606" T	66,682		Control Point

CBAL	1° 15' 22.1294" S	116° 50' 22.9732" T	75,049	Control Point

The result analysis from GNSS adjustment also indicate from the ellipse semi-major axis for each measurement point from Benchmark to Control point, for the observation in BM HP.64.09.046 categorized as geodetic survey for national scale. For TB.01 and TB.02 classified for geodetic survey for regional class. These data also conform the standard for GNSS static survey standard in Indonesia.

3.2 Hydrographic and Oceanography Data

3.2.1 Bathymetric Data Result

- Quality Control Data

Quality control of bathymetric data are analysed for 21027 Multi Beam data, and resulted as below:

Total Data	Order Percentage				Not Passed	Total Percentage
	Exclusive	Special	1A/1B	2		
21027	87%	8.1%	4.7%	0.2%	0%	100%

According to 95% level of confidence data, the depth TVU of the bathymetric data is classified to special order.

- Sounding Result

After the calibration, verification, and bathymetric data correction, the depth data could be further analysed. The data will be compared to Indonesia Nautical Chart and the meticulous sheet using GIS software. Sounding quantity are materialize 100% according to the area of interest for survey. The MBES survey are fully coverage for the large river, and for the tributary river are covered by Single Beam Echosounder with the scale of 1:5000. The overlay Digital Terrain Model with Nautical Chart and Satellite Imagery can be shown below.

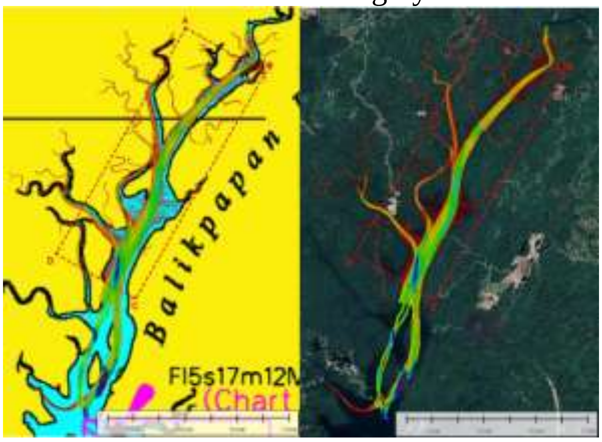


Figure 12. Overlay Bathymetric Data

3.2.2 Tidal Data Ouput

Based on the tidal data survey for 3 days and 14 hours, the average value of the Chart Datum is the result based on calculation using British Admiralty. The result for each Chart Datum is shown in the table below :

Tidal Station	**Location**	**Chart Datum (cm)**
Main Station	Jetty Port PT SGP	241
Station Comparation-1	Beaching Port PT HBH	239

Station Comparation-2	Ponton Port PT ITCIKU	207

According to the tidal observation at Jetty Port PT SGP for 29 days, resulted in tidal harmonic constituent value, as shown in the table below :

Tidal Harmonic Constituent at Main Station

	S_0	M_2	S_2	N_2	K_1	O_1	M_4	MS_4	K_2	P_1
A cm	244	68	55	8	27	17	7	14	15	9
g^o		167	224	155	281	260	88	128	224	281

Based on tidal harmonic constituent value, the type of the tidal is classified using Formzahl equation as shown below :

$$F = \frac{A(K_1) + A(O_1)}{A(M_2) + A(S_2)}$$

Whereas,

F : Formzahl Value

$A(K_1) + A(O_1)$: Amplitude constituent harmonic for diurnal

$A(M_2) + A(S_2)$: Amplitude constituent harmonic for semi-diurnal

Based on the equations, the Formzahl value for tidal main station is 0.36, then the tidal characteristic in Sepaku River could defined as Mixed Tide Prevailing Semi Diurnal. In a day, there is two pairs a day and night with different heights and interval.

3.2.3 Levelling

Levelling measurement required to define the Benchmark Elevation regarding the tidal data survey. The benchmark elevation in BM HP.64.09.046 referred to Chart Datum can be defined below :

a) Elevation of BM HP.64.09.046 to Zero Palem : 444.3 cm
b) Chart Datum Elevation to Zero Palem : 241.0 cm
c) Elevation of BM HP.64.09.046 to Chart Datum : 203.3 cm
d) Z_0 : 180,0 cm
e) Elevation of BM HP.64.09.046 to LAT : 383,3 cm
f) Elevation of LAT to Zero Palem : 61,0 cm

The illustration of BM Levelling to Tidal Observation can be shown below :

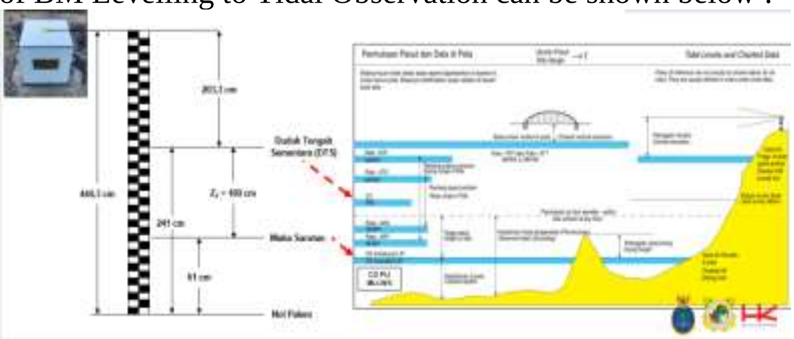
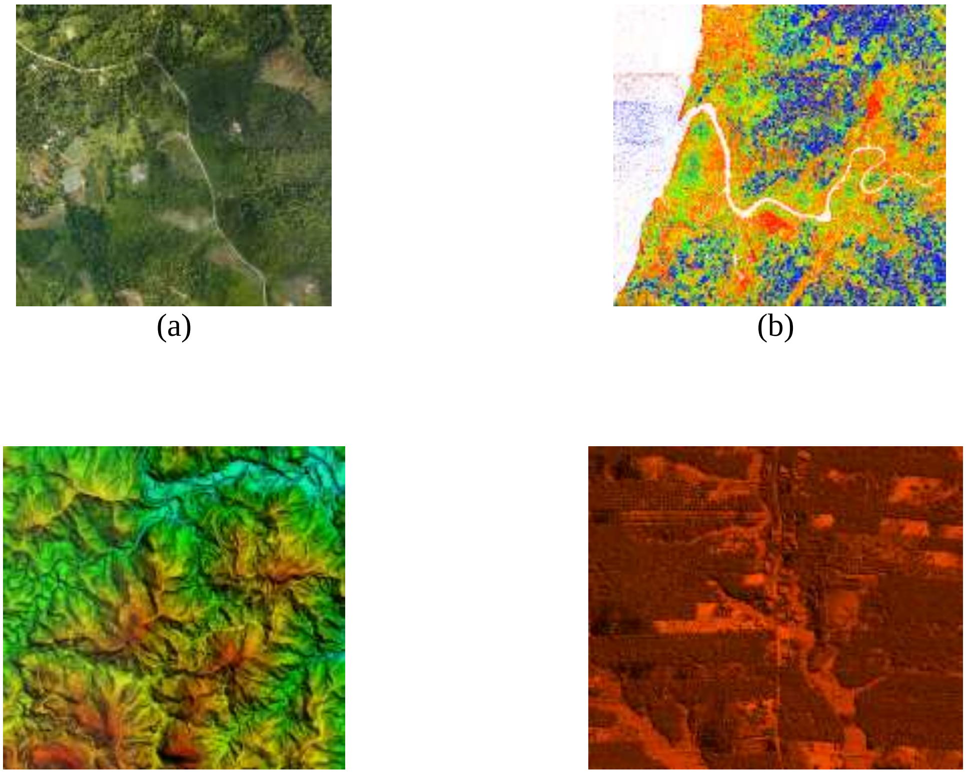


Figure 13. Configuration of Bechmark Elevation regarding Tidal Data Survey

3.3 Topographic Data LiDAR and Bathymetric

Existing topographic data are obtained from airborne lidar survey for specification scale 1:5000. Airborne LiDAR Data had been acquired from June to August 2019 using fixed wing aircraft with camera and lidar sensor. The camera sensor is Leica RCD 30 is built integrated with lidar sensor of Leica ALS 70. Focal length of the camera is 53mm and the flying altitude is 1115 above MSL. The output of both sensors are the image RAW with GSD of 9 cm and the density of 3D point cloud is 13 ppm. The existing Airborne LiDAR data in the shore area could be shown below.



(a) (b)

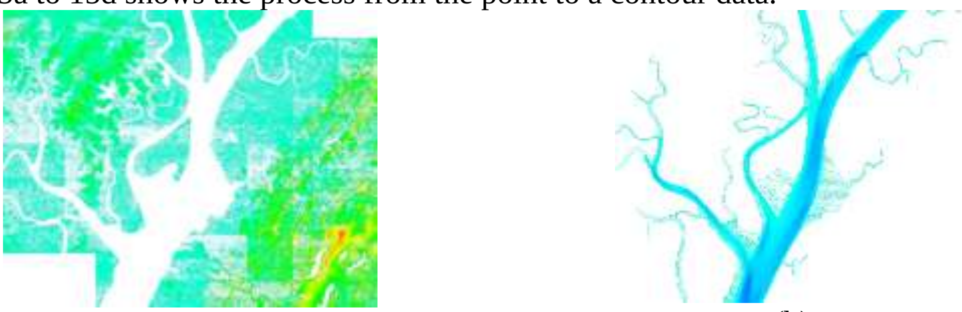
(c) (d)

Figure 14. (10a) Aerial Imagery from Airborne LiDAR, (10b) 3D Point Cloud already classified, (10c) Digital Terrain Model (DTM), (10d) Digital Surface Model (DSM)

3.4 Data Deliverable

After matching the elevations of LiDAR point cloud and hydrographic data based on the same vertical datum reference which was MSL, the process followed by creating the DTM with resolution 1m x 1m and generating contour lines.

Figure 15a to 15d shows the process from the point to a contour data.



(a) (b)

(c)

(d)

Figure 15. (15a) Ground LiDAR with elevation reference are refer to Benchmark HK.64.09.046, (15b) Bathymetric Data in River Area (Point), (15c) Digital Terrain Model from combination of Ground LiDAR and Bathymetry, (15d) Contour Data derived from DTM in fig. 15c.

4 CONCLUSION AND RECOMMENDATION

The conclusion can be concluded from this paper are :

1. The hydrographic survey in Sepaku River produce the large scale underwater topographic map which comply with the special order regarding the 95% confidence level based on IHO standard.
2. The result of the data combination between topographic and hydrographic data could provide large scale map 1:5000 which referenced in same vertical datum regarding the Basic Design stage for Immersed Tunnel.

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