Datum Verification for Coastal Engineering Studies

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DOI: https://doi.org/10.30880/ijscet.2024.15.03.021

Article Info

Abstract

The precision of a vertical datum, used as a reference point for elevation measurements, is essential for calculating mean sea level and tracking changes along the coast. This ensures consistent and trustworthy data for managing flood risks, erosion, and infrastructure planning. This research paper focuses on verifying the vertical datum for coastal engineering studies at Batu Pahat, Johor, using Global Navigation Satellite System (GNSS) technology. Levelling work are carried out to establish accurate height measurements relative to a vertical datum, the resulting data are used to obtain reliable readings from the tide gauges. This process is crucial for coastal studies, as it allows researchers to compare current data with historical records and understand changes in sea level over time. The research focused on two main locations, Kg Parit Kuda and Kg Parit Sungai Bagan, representing the Batu Pahat shoreline, using digital leveling techniques to collect data. The Mean Sea Level (MSL) at Kuala Batu Pahat was measured to be 1.59 m above Chart Datum (CD), with slight shoreline variations noted based on the latest 1-year CD observation established in 1979 by the National Hydrographic Center of the Royal Malaysian Navy. The project's success is attributed to the acceptable differences between observed values, which confirmed the reliability of the established Land Survey Datum. This study showcases the importance of datum verification in coastal engineering applications to mitigate potential risks and ensure accurate measurements for future development projects.

1. Introduction

Datums is a reference for surveying, providing a consistent framework for determining precise elevations and horizontal positions, which is essential for the proper alignment and execution of civil engineering projects, ensuring accuracy in construction and infrastructure development. A geodetic datum is an abstract coordinate system that use mean sea level as reference surface for surveying and mapping [1]. Geodesists and surveyors rely on datums to establish initial or reference points necessary for mapping boundaries, making floodplain maps, designing levees, carry out construction surveys, and other tasks requiring precise coordinates. Positions on Earth and other celestial bodies can be accurately represented with geodetic coordinates. There are two main categories

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of datums, horizontal and vertical. The basic information required to determine the height or elevation of positions on Earth's surface is a vertical datum. This data served as the baseline or zero height reference surface [1]. The horizontal datums are equator and Greenwich meridian used to measure latitude and longitude on the earth surface. [2]. The vertical datum is a collection of specified places on earth with established heights above or below mean sea level. The form of the geoid determines the mean sea level in places that are away from the coast. Land surface elevations are measured using geodetic vertical datums. Water surface elevations are referenced to nautical charts with bathymetric sounding values. Geodetic surveys measurement at tidal gauges are used to convert between these land and water surface elevations.

Early January 2022 there was a huge tide event in Malaysia, causing flooding in Batu Pahat. Because of mangrove loss, much of Batu Pahat's west coast bund region is now directly exposed to the sea. Natural habitats like mangrove could protect coastal communities against the impacts of waves and storms, reducing chronic shoreline erosion, promoting shoreline accretion, and making circumstances favourable to wetlands reproduction, they can also attenuate wind-waves and swells [3]. If unprotected, high tidal flooding will inundate low-lying locations due to sea level rise. Despite recovery efforts, similar tidal flooding events continued into 2023, highlighting the ongoing vulnerability of Batu Pahat's coastal areas. Therefore, there is a pressing need for continued research into flood mitigation strategies and habitat restoration to enhance the region's resilience to future disasters and sea-level rise.

Two main surveying techniques have been used for a long time to produce topographic maps and ocean charts. LSD (Land Survey Datum) and CD (Chart Datum) are essential for managing coastal zones and marine areas in a systematic and sustainable way [4]. The LSD is a reference level used to define the relationship between Mean Sea Level (MSL) or geoid on land, and the actual MSL in hydrographic charting. On the other hand, the CD is a crucial reference level for navigation and maritime activities, providing safe passage for vessels along the coast. The separation of LSD and hydrographic CD value is necessary to ensure a consistent height datum across the land and sea interface [4] along the coastline and it allows for a more structured and sustainable management of coastal zones. However, factors like climate change, sea-level rise, and tectonic movements can impact existing structures along coastlines, as seen in Batu Pahat. To address this, a study using Global Navigation Satellite System (GNSS) was conducted to verify vertical datums for coastal engineering along Batu Pahat's shoreline, specifically in Kg Parit Sg Bagan and Kg Parit Kuda shown in figure 1 below. This verification is critical for ensuring accurate and updated topographic and hydrographic data for effective coastal management.
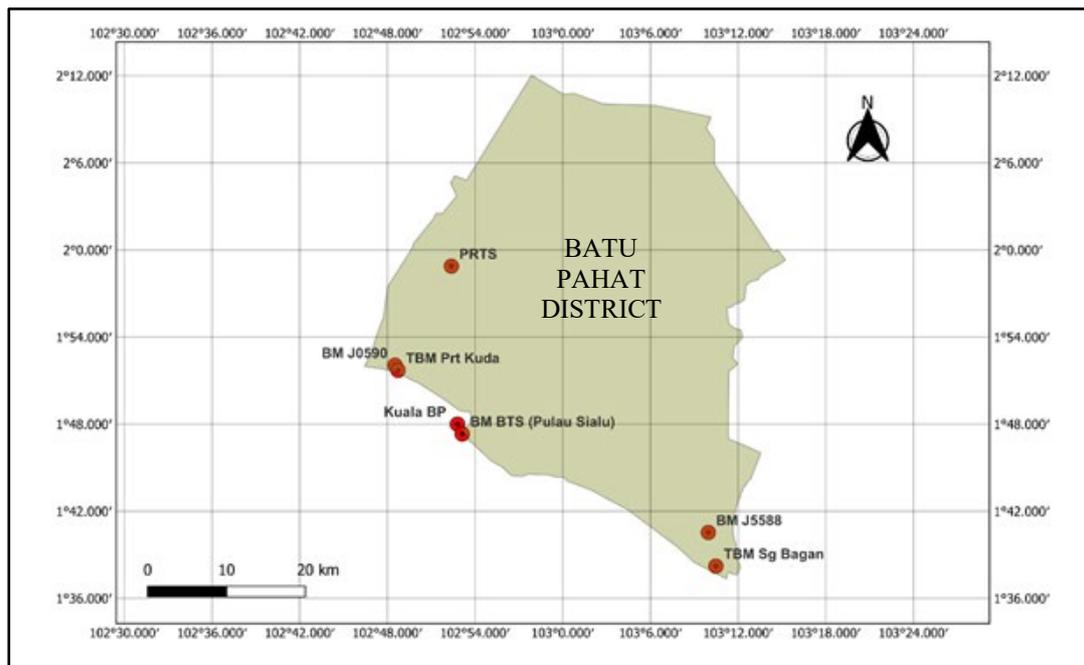

Fig. 1 *Research area*

2. Literature Review

The surface of Batu Pahat's coastal region is highly susceptible to erosion and degradation, particularly along the exposed west coast where mangroves have been lost. The soil in these areas, often low-lying and waterlogged, faces regular tidal inundation, which weakens its stability and increases vulnerability to further erosion. Without natural barriers like mangroves, the coastal soil is directly impacted by wave action and storm surges, worsening

erosion and making the area prone to flooding and sediment loss. In the study of Batu Pahat's coastal region, two key areas have been selected at opposite ends of the district, representing the outer boundaries of the study area shows in figure 1. A central point between them has also been identified, which contains secondary data relevant to the research. Together, these three points, two at the district's ends and one in the middle. Effectively represent the entire coastline, providing a comprehensive overview of coastal conditions across Batu Pahat.

2.1 Land Survey Datum

Land Survey Datum 1912 also identified as LSD12, is the first official national vertical datum [5]. The first precise levelling network known as First Order Levelling Network 1967 (FOLN67) referred to LSD12 as a vertical datum. A land survey datum establishes a reference level for land surveying activities, often above Mean Sea Level (MSL) [6]. A set of mathematical models and definitions known as a LSD serves as a starting point and frame of reference for the measurement and mapping of geographical features on the surface of the Earth. It provides a standardized system for defining locations and elevations, ensuring consistency in geospatial measurements and mapping. Land survey datums were linked to specific benchmarks or visible rocks, predating unified land-leveling systems [7].The accuracy and efficiency of geodetic measurements in land surveying have significantly improved with electronic devices capable of simultaneous angle, distance, and height measurements. In Peninsular Malaysia, including the islands of Pulau Pinang, Pulau Langkawi, and Pulau Tioman, is covered by the FOLN67 developed to offer vertical control via benchmark. This vertical datum was used for all land surveying and mapping operations [1]. Otherwise, land survey datums play a crucial role in ensuring the accuracy and effectiveness of land survey data collection and analysis. Various methods and technologies are employed to improve the precision of land survey data, such as remote sensing surveys [8].

2.2 Chart Datum

A chart datum is a reference level or elevation used to measure and record the depths of water in a specific location. It is normally established by the national or local hydrographic office and serves as a reference point for nautical charts and used in hydrographic surveys for safety of navigation, ensuring consistent depth measurements by accounting for tides and vessel dynamics [9]. Chart datum tidal data refers to the precise measurement of water levels used as a reference for various marine activities. Studies have shown that the determination of chart datum requires accurate tidal observations over extended periods to achieve high precision [10] The chart datum is commonly defined as the lowest astronomical tide, which has traditionally been represented in many locations by the constituent-based Spring Low Water [11]. The Chart datums are statistically derived from the averaged levels of peaks and troughs observed in a sea level time series, also known as peak-based tidal datums. Both systems rely on a reliable and near continuous monitoring of water levels for an appropriate period of time at the site of interest, preferably 19 years to account for change across the 18.61-year nodal tidal cycle [11]. The observed tide data from a period of one month (short term), six months, one year to a maximum period of 18.6 years (long term).

2.3 Tide Gauge

A tide gauge is typically equipped with a graduated staff or other reference on which the water level can be seen clearly. The purpose of installing a tidal gauge is to calculate a continuous time series of sea level. The Department of Survey and Mapping Malaysia (JUPEM) is the main government organization in Malaysia that acquires, processes, archives, and distributes tidal data. JUPEM provides Malaysia's tide gauge station data to the Permanent Service for Mean Sea Level (PSMSL) monthly and annually. For the Peninsular Malaysia has 12 tidal stations and along the coast of East Malaysia have 9 tidal stations [12]. Networks of tidal gauges in ports and harbours have been monitoring coastal sea levels for decades, set up by a wide variety of institutions to meet their specific needs and requirements. Most of these networks were first inspired by the need to better anticipate tides, define datums, and facilitate port operations [13]. In most coastal areas, the main influence on low-frequency water levels recorded by the gauge is the gravitational pull of astronomical tides [14]. Astronomical tidal predictions are made using established data analysis and prediction methods, such as those employed by the National Hydrography Centre of the Royal Malaysian Navy (RMN) and others. The Royal Malaysian Navy relies on accurate chart datum for its coastal engineering operations, which include precise hydrographic surveying and maritime baseline determination. Studies in Malaysia have shown that it is crucial to have precise chart datum due to the impact of rising sea levels on mean sea level and chart datum values [15], [16].

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3. Methodology

3.1 Acquisition Data

This study's data acquisition process involved using high-precision GNSS technology and supporting tools to collect accurate geospatial information. The equipment used throughout this study uses Topcon Hiper V. The HiPer V can be used as a base station and rover receiver for machine control and other high-accuracy applications. It is designed to work with Topcon's MAGNET Field software for data collection and processing [17].

GNSS is a common term describing any satellite constellation that gives positioning, navigation, and timing (PNT) services on a global or regional basis using a network of ground receivers [18]. The systems can provide geospatial location data with millimetre-level accuracy anywhere within the network and presently accessible for many surveying and mapping services, including establishing control, setting out, real-time deformation observing and on-board camera positioning for aerial photography. GNSS receiver use to determine the position and height value for the selected monitoring points. The height obtained via GNNS for each monitoring points can be use for verification by comparing with the existing height refer to LSD and CD datum. In addition, the National Hydrography Centre of the Royal Malaysian Navy's tide tables for 2022 shown below are applied to compute the difference between LSD and CD values.

Table 1 *National Hydrography Centre of the Royal Malaysian Navy's tide tables for 2022*

Description	Abbreviation	Predicted Tidal Level (m)	
		Chart Datum, CD	Mean Sea Level (MSL)
Highest Astronomical Tide	HAT	3.37	1.78
Mean High Water Spring	MHWS	2.75	1.16
Mean High Water Neap	MLWN	2.03	0.44
Mean Sea Level	MSL	1.59	0.00
Mean Low Water Neap	MLWN	1.15	-0.44
Mean Low Water Spring	MLWS	0.43	-1.16
Lowest Astronomical Tide	LAT	0.00	-1.59

3.2 Procedure

In this study, Static GNSS are used for surveying method. For control surveys, the instrument used by dual-frequency static methods, which provide the maximum precision (sub-cm) possible with GNSS for baselines of less than 100km. They require for GNSS data from four or more widely used satellites to be observed simultaneously at base and rover station. The static GNSS data enables greater precision in geodesic and topographic surveys, allowing for georeferencing precise surveying networks in Civil Engineering and yielding a global RMSE of 1 cm under optimal conditions [19]. The method works by utilizing two GNSS receivers. These receivers are placed at each end of a line to be measured. One of the receivers positioned at the control or base station with the known coordinates at nearest benchmark provided by JUPEM. While the second receiver was setup at the location or point where the coordinate needs to be determined. Figure 2 shows how GPS observation works. Table 2 shows the duration of the observation period varies depending on the distance between base and rover and the accuracy required for the static GNSS measurement technique [20]. Since the distance between base and rover station less than 20 km,1 hour of observation was required. Due to the static method used throughout the monitoring process, projection used is Malaysia_CS2000-Johor because this projection has been confirmed stable and widely used for observation process that require high accuracy data. The datum used is GDM2000 because GDM2000 is totally compatible with satellite-based navigation systems such as the GPS and with major international geographic systems [21]. Peninsular Malaysia uses the WGEOID04 Geoid model; each country uses a different Geoid model. Geoids are used to identify a point's actual height above the earth's surface. If a geoid value is not provided, the height is calculated with reference to ellipsoid. The recording rate for this monitoring method has been changed to 1 second to assist the GNSS receiver in acquiring more data. A considerable amount of observational data was produced by a more exact and precise coordinate value. The current value for the elevation mask is 15 degrees. Therefore, any satellite 31 signal with an angle of less than 15 degrees won't be detected by the GPS receiver. In this study, a temporary benchmark was established with accurate elevation via GNSS for each site.
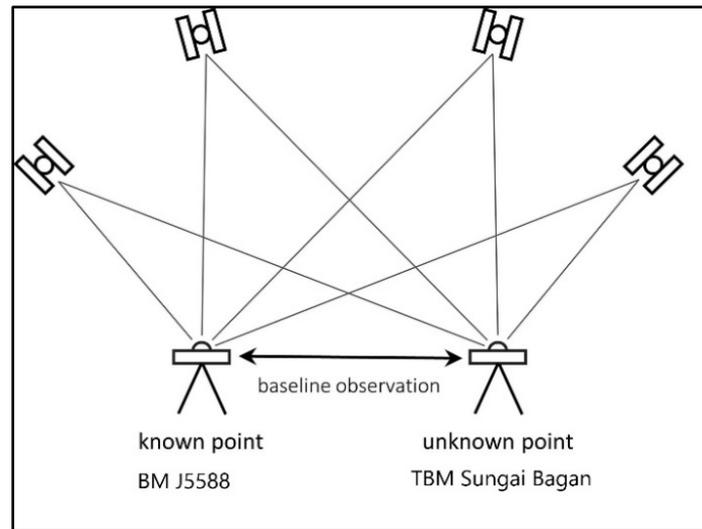
Fig. 2 GPS observation

Table 2 *Potential accuracies in horizontal (H) and vertical (V); accuracies are given as one sigma (σ) [21]*

| Method	Observation	Baseline Length	Occupation Time	Accuracy
Static Baseline	Dual frequency	20km	>1h	H 5-10mm
		30km	>2h	V 10mm
		50km	>4h	
		100km	>6h	

The selected reference point is a Continuous Operating Reference System (CORS) Station in Parit Sulong refer by figure 1. CORS is a system of RTK networks that share corrections information and send it out to selected monitoring point, typically over the internet. With this network, accuracy is improved because it takes multiple stations to provide accurate location and prevent a false initialization of a single base station [19]. Utilizing Continuously Operating Reference Station (CORS) networks for static Global Navigation Satellite System (GNSS) measurements offers the benefit of consistent repeatability and high accuracy for real-time positioning applications and the creation of detailed topographic maps. CORS networks provide a stable and reliable infrastructure that enhances the precision and reliability of GNSS measurements, making them invaluable for a wide range of geospatial and surveying applications [22]. The CORS data is essential for establishing a network of monitoring nodes and plays a crucial role in the data processing activity using Magnet Tools software. Once the receivers record the data, it will be transferred to the computer via the controller and processed with the Magnet Tools software. This program can edit and refine data from field surveys conducted using total stations and GNSS.

The GNSS receiver manufactured by Topcon provides results in Topcon's proprietary (*.tps) format. In GNSS data processing, observational data is transformed into the RINEX format, which allows data exchange between GNSS programs. The data recorded on a memory card in the GNSS field receiver is processed using CORS information with base and rover stations to access the network. The geographic coordinates for CORS station in Parit Sulong show in Table 3 below.

Table 3 *The WGS-84 geographic coordinates system for CORS station at Parit Sulong*

Point name	Latitude	Longitude	Elevation(m)
PRTS	1.981407989	102.8730614	11.485

Therefore, levelling work is used to describe any method for establishing or comparing relative heights. It is an important step in gathering information for use in mapping, engineering design, and building [23]. It is used to determine a point's elevation with respect to a datum or to determine a point's height with respect to a datum. In order to ensure that the reading of the tide gauge is relative to the LSD or CD value, a levelling work was performed as part of this project using digital levelling and staff shown in figure 3. A temporary benchmark has been set up there to serve as a reference for the next point, which will have precise coordinates and an accurate elevation from GNSS observations.

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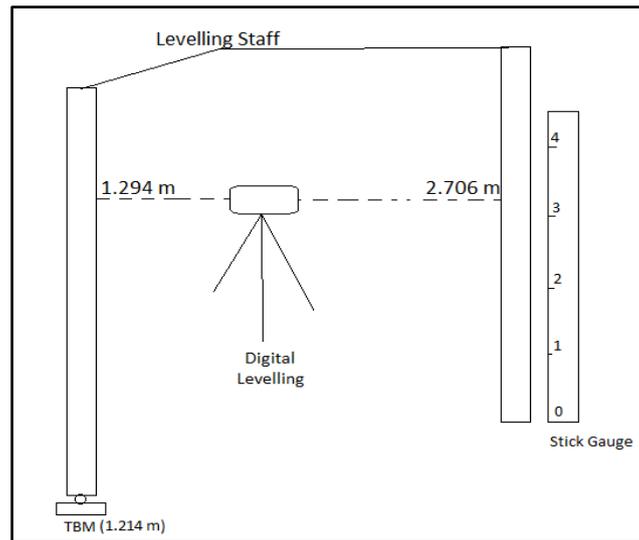
Fig. 3 *Levelling work on tide gauge*

4. Result and Discussion

Data observation on a benchmark near the project site is taken for 1 hour to determine its position and height. The data collected must be compared with the current values provided by JUPEM, which were observed and recorded in 2012 and 2015. To select the appropriate benchmark for the observation of the following points, a benchmark verification observation was carried out. The benchmark will be chosen based on minimal variations in its height values. The height and position of a benchmark may change due to factors such as soil deposits. Based on table 4, BM J5588 and BM J0590 were selected as base for the following monitoring point in Parit Sg Bagan and Parit Kuda. To achieve the objective of the study on the difference in the value of CD and LSD, monitoring needs to be done for both datums at same location. Since the tidal gate is easy to monitor the water level during tidal phenomena, a temporary benchmark is set up at the tide gate near to the study area. All selected locations are displayed in figure 1. The results of the study will show the relationship and level comparison between points in Parit Sg Bagan, Parit Kuda and Kuala Batu Pahat refers to the datum of LSD and CD. All LSD positioning is reference to PRTS CORS station (for Latitude & Longitude), while the heights were referred MSL value from JUPEM benchmark close to the TBM at study locations. Meanwhile, at the tide gauge stick, the reading should be referred to the CD value. The result of the comparative analysis of the datum and water levels in Parit Sg. Bagan and Parit Kuda was compared with Kuala Batu Pahat CD value which is obtained from the harmonic constant published by the National Hydrographic Centre (NHC).

Table 4 *Summary of GNSS static observation at Kg Sg Bagan and Kg Parit Kuda*

Point name	Latitude	Longitude	Elevation(m)	Horz RMS (m)	Vert RMS (m)
BM J5588	1.675557553	103.1661224	1.605	0.001	0.003
TBM Sg Bagan	1.636944372	103.1747449	1.214	0.001	0.003
BM J0590	1.867767239	102.8088409	1.95	0.002	0.003
TBM Parit Kuda	1.861855153	102.8122073	1.397	0.001	0.003

4.1 Land Survey Datum

Based on Table 3, BM J5588 and BM J0590 have been used as reference benchmarks to setup GNSS receiver (served as base station), while another pair of GNSS receiver (served as rover) were setup at TBM located close to tide gauge at Parit Sg Bagan and Parit Kuda, respectively. The GNSS static observation data then processed using Topcon Magnet Tools software. This setup allowed for high-precision measurements, with the base station providing a fixed reference point for the rover's positional data. Various accurate evaluations can be carried out based on the kinds of errors that require evaluation. The RMSE approach is widely used for systematic error evaluation [24]. In general, the horizontal and vertical RMSE value attained via GNSS static observation is less than 5mm as shown in Table 4, respectively. This level of accuracy is crucial for applications requiring precise

geospatial data, especially in coastal monitoring where even small measurement errors can significantly impact data interpretation.

4.2 Levelling Works

By direct levelling, the vertical distance between two points is calculated without considering their relative horizontal positions. Stick gauge reading was determined by the value of a TBM established near the site location. Digital readings of bar codes on the staff and rod inputted into the level and displayed on the device [23]. According to Figure 4, The diagram illustrates the process of datum checking with a stick gauge and a levelling instrument. The levelling staff is placed precisely at the zero-reading position on the stick gauge to establish a reference point, and the horizontal sight line is used to measure height differences. This setup allows precise determination of elevation differences and verification of height data against established datums.
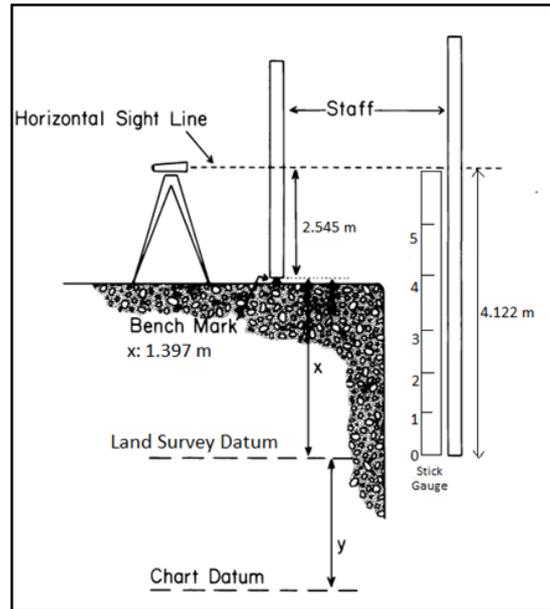

Fig. 4 *Datum checking of visual stick gauge*

Table 5 *Data collection levelling work*

Point	Staff Reading (m)	Heght(m)	Differences (m)
Location: Kg Parit Sg Bagan			
TBM	1.294	1.214	(0.19)
Stick Gauge	2.706	0	
Location: Kg Parit Kuda			
TBM	2.545	1.397	(0.17)
Stick Gauge	4.111	0	

4.3 Chart Datum

Tidal levels are given as a height above Chart Datum. However, the Mean Sea Level (MSL) can be used as a rough approximation of the CD and LSD for the purposes of this reporting. The Royal Malaysian Navy employs various methods for tide prediction, including harmonic analysis, wavelet-based models, and artificial neural network forecasting [25]. These methods are reliable and accurate, supporting tidal analysis and prediction for maritime activities and coastal management in Malaysia.The Kuala Batu Pahat tide levels as issued by the National Hydrography Centre of the Royal Malaysian Navy, (RMN) states that the value of Chart Datum, CD is 1.59m when value of Mean Sea Leve (MSL) is 0m and the value is obtained of 1 year observation in 1979. Since the determination of CD extremely takes a long period of observation, the tidal prediction data is used in the determination of chart datum in this study area. Using tidal prediction data to determine the Chart Datum (CD) is a practical solution when long-term tidal observations are too time-consuming or costly. This method helps establish a reliable Chart Datum without needing extensive observation periods. Therefore, an observation data was extracted from Project Coastal Johore West in this study to verify the difference value between LSD and CD.

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The survey work that was conducted on Pulau Sialu are further verified the value of 1.59 m.

According to the information provided, the reduce level BM BTS is 9.39 m above CD. Two hours of continuous GPS monitoring at BM BTS and BM J0633 at bandar Batu Pahat, were used. The processed data reveals a BM BTS of 7.997 m. Regarding to RMN, BM BTS stands at a height of 9.39 metres above ground level (CD). However, BM BTS is 7.997 with reference to LSD, hence the difference in height between them is (CD) 9.39 - (LSD) 7.997 = 1.393 m. As a result, there is a slight disparity in the values since the BM BTS is located in the middle of the ocean, while the data for Kuala Batu Pahat is collected on land. If BM BTS is located on land, the value will be close to 1.59. Therefore, along Batu Pahat coastline value is thought to be the same as Kuala Batu Pahat Port.

4.4 CD Comparison to LSD

The value of CD in Kuala Batu Pahat is 1.59 below the MSL. Considered the value to be the same for all locations along the shoreline of Batu Pahat. The calculation of the value that represents the difference between LSD and CD at Kg Sg Bagan and Kg Parit Kuda are depicted in figure 5. Figure 4 explains that the number 0m on the stick gauge reading refers to the MSL or LSD value. Since the value of CD was 1.59 m used for each of the locations that were picked. The difference value between LSD and CD could be defined as the value of Above Chart Datum (ACD) for each location. The CD value in Kg Parit Kuda was 1.39 ACD while the CD value at Kg Sg Bagan was 1.42m ACD.
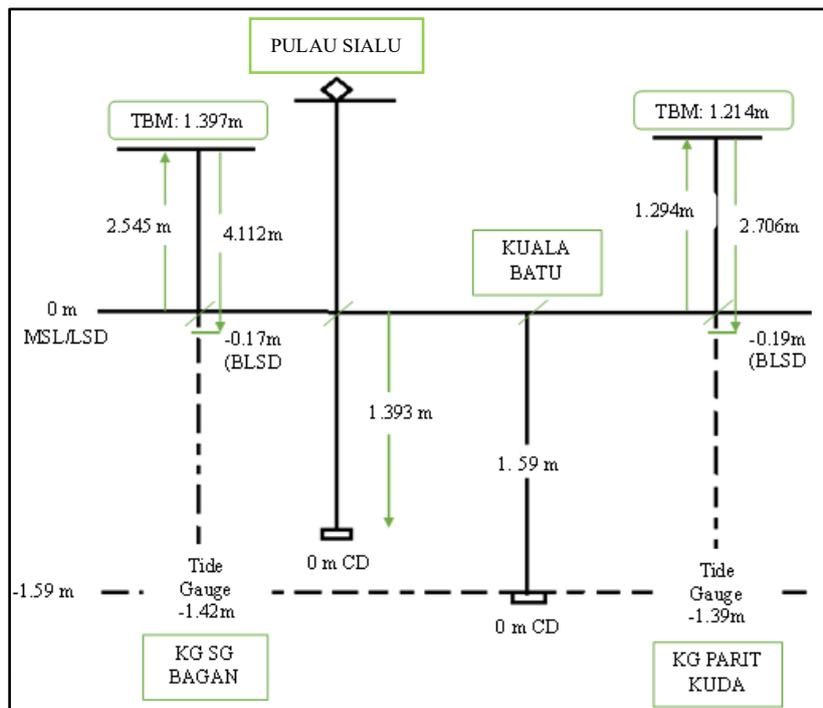

Fig. 5 *Calculation the difference value between LSD and CD*

5. Conclusion

The precisely measured coordinates of a TBM point near the tide gauge was used to monitor the tides. Using a static approach for GNSS technology, the Land Survey Datum was established with a high degree of accuracy and precise for height determination. The readings in Batu Pahat are cross validated with reference to the TBM for the range between 0.17 to 0.198. Time limitations prevented sufficient data from being gathered at the selected site for Datum Chart evaluation. Data collection on water levels necessitates continuous observation since sea wave heights are continuously changing. It is crucial to consider mean sea levels over a long period to monitor changes. We discovered that the MSL value above the CD at Kuala Batu Pahat is 1.59 while considering the most recent 1-year CD observation, which was established in 1979 by the National Hydrographic Center of the Royal Malaysian Navy. The Batu Pahat location expected difference between LSD and CD is 1.59 but there was a variation of 0.2m observed. In conclusion, it is essential for each location to conduct its own study to determine the accurate Chart Datum (CD) value, rather than relying on the nearest available CD value. This approach ensures optimal results for structural projects, particularly coastal structures such as bunds. Properly determining the CD value is crucial for setting the correct height of these structures to prevent seawater from entering drainage systems, which can

lead to high salinity levels in freshwater irrigation and cause significant damage to property, crops, and plants. The probable explanation for this variation may be accounted to errors occurred during transfer of benchmarks to the monitoring points. The disparity between the readings is under acceptable limits. The mean sea level monitoring will be practised cautiously to minimize errors because all the tidal observations are made using LSD reference values.

Acknowledgement

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contribution

The authors are responsible for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting.

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