Sriwijaya Journal of Environment
Article
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Precision Bathymetric Survey for Marine Infrastructure: A Case Study of Bullnose Jetty, Lagos, Nigeria

Alfred Sunday Alademomi[1,2], Joseph Olayemi Odumosu[3], Stephen Olushola Oladosu[3]

[1]*Department of Surveying and Geoinformatics, Faculty of Engineering, University of Lagos, Akoka, Lagos State, Nigeria*
[2]*Centre for Multidisciplinary Research and Innovation Suite C59, New Bannex Plaza, Wuze 2, Abuja, Nigeria*
[3]*Department of Geomatics, Faculty of Environmental Sciences, University of Benin, Edo State, Nigeria.*
**Corresponding Author: olushola.oladosu@uniben.edu*

Article history

Received	Received in revised form	Accepted	Available online
12 January 2025	10 March 2026	10 March 2026	28 March 2026

Abstract: A precision bathymetric survey was conducted at Bullnose Jetty, Apapa, Lagos, ahead of piling and repair activities. The survey employed a single-beam echo-sounder coupled with GNSS positioning and produced high-resolution 0.1 m grid data. Depths across the study area ranged from 10.1 m to 13.2 m relative to the measured surface elevation. Probing at proposed pile points (A-38_new, A-39_new, A-40_new) found no obstructive debris, and the broken pile (P39A) was located and mapped, lying flat on the seabed. These results informed safe pile placement and confirmed the suitability of the repaired pile positions. The study provides one of the first high-resolution bathymetric validations focused on damaged-pile assessment at Bullnose Jetty, Lagos, filling a local demand for precision in-situ seabed evaluation for maintenance and repair planning. Practical implications include improved pile-driving planning, reduced risk of pile collision with submerged debris, and enhanced operational safety during repair works.
Keywords: Geospatial analysis, Costal engineering, Pilling, Positioning, seabed morphology, marine

1. Introduction

The socio-economic usefulness of a jetty in an urban coastal area is significant for both transportation and economic benefits. Jetties facilitate the movement of passengers and goods by providing an alternative to road and rail transport, helping reduce traffic congestion in urban areas [1]. They also support tourism by acting as entry points for cruise ships and ferries, which boosts local businesses such as hotels, restaurants, and tour services. The fishing industry benefits from jetties by offering docking facilities for fishermen, contributing to food security and local economies [2]. Jetties play a role in trade and commerce by enabling the import and export of goods, lowering transportation costs for businesses. They also create direct and indirect employment opportunities in sectors like port operations, security, and local services, driving economic activity in surrounding areas [3]. The presence of a jetty often leads to further infrastructure development, such as improved roads and commercial facilities, which enhance urban growth and living standards.

Environmental sustainability is also supported by properly designed jetties, which help manage coastal erosion and, in some cases, host renewable energy projects like offshore wind farms [4]. According to [5], jetties serve a social function in community hubs and promote social cohesion as well as offering recreational opportunities, while in some regions, they hold cultural significance as symbols of maritime heritage.

The dynamic interaction between jetties and the marine environment also leads to changes in local bathymetry and sediment dynamics, which have been documented in studies such as [6]. These changes can have lasting effects on marine structure stability, navigability, and coastal morphology. A jetty survey may be informed by various factors, including construction and design requirements for new structures, where accurate site and underwater data are crucial. Structural integrity checks driven by routine maintenance schedules or visible signs of wear, such as cracks or corrosion, also necessitate surveys [7][8][9]. Environmental changes, such as severe weather events or sedimentation shifts, may prompt assessments to evaluate impacts on the jetty and surrounding waterways [10]. Operational challenges, like vessel grounding or berthing difficulties, often lead to surveys to identify and address underlying issues [11][12]. Regulatory compliance further drives the need for periodic surveys to meet environmental and safety standards [13]. Besides, expansion or modification projects rely on updated site information to align with existing conditions [14]. Economic considerations, such as optimizing operations and reducing downtime, also play a role in initiating surveys to support efficient and cost-effective maintenance or upgrades [15].

Badejo & Adewuyi (2019) [16] described bathymetric surveys as a cornerstone in marine infrastructure development, offering vital insights into underwater topography and conditions critical for engineering applications [17]. At Bullnose Jetty, Apapa, Lagos, this survey was carried out as a pivotal step in assessing seabed conditions to guide piling and repair operations. The scientific basis of this work revolves around echo-sounding principles and geospatial analysis, which together enable the precise mapping of underwater environments.

Despite the importance of Bullnose Jetty to Nigeria's maritime economy, limited research has integrated high-resolution bathymetric data with structural assessment for this location. Thus, this study addresses the gap by applying advanced geospatial tools to ensure structural safety and functional continuity. Jetties are critical coastal infrastructure that support cargo handling, vessel operations, and local economic activities. However, damage to structural elements such as the broken piles and localized seabed changes can compromise safety and complicate repair operations. Precision bathymetric surveys provide essential site-specific data for engineering decisions by mapping seabed topography, identifying debris, and validating pile clearance before repair works. To date, there are limited regional studies that apply high-resolution bathymetry specifically to the validation of damaged and replacement piles in the Apapa/Bullnose Jetty context. This study addresses that gap by performing a precision bathymetric and probing assessment of proposed pile locations (A-38_new, A-39_new, A-40_new), mapping the broken pile (P39A), and evaluating seabed conditions relevant to piling and repair. Our objective is to (i) determine seabed depths relative to the water surface, (ii) confirm the presence or absence of obstructive debris at proposed pile points, and (iii) precisely locate the broken pile to inform safe repair operations. The novelty of this work is that it provides one of the first high-resolution, engineering-focused bathymetric validation datasets for damaged-pile assessment at Bullnose Jetty, Lagos, combining GNSS-referenced echo-sounder data with targeted probing and video verification.

2. Materials and Methods

2.1. Description of Study Area

The Bullnose Jetty is located within the Apapa Port Complex in Lagos, Nigeria, a major maritime hub in West Africa. The jetty serves as a key infrastructure for cargo handling and berthing operations, contributing significantly to the region's economic activities. Its geographical coordinates (543749.385Em; 711360.136Nm and 543769.794Em; 711377.151Nm) place it along the Lagos Lagoon, characterized by a tidal environment with varying depths and sediment compositions. The area experiences moderate maritime traffic and is subject to dynamic hydrodynamic forces due to its proximity to open sea channels.

The choice of the study area reflects its critical importance to jetty's operational integrity and the need for precise geospatial and structural assessments. To ensure accuracy in tidal correction, water level data were concurrently collected using a tide gauge installed at a stable point along the quay wall. Tidal elevation values were recorded every 10 minutes throughout the survey duration. The corrected depth (Dc) was calculated using equation 1.

$$D_c = D_m - h_t \quad (1)$$

Where: D_c is the required corrected depth, D_m is the raw measured depth, and h_t is the tidal height above chart datum. These values were synchronized with GNSS timestamps to ensure precise correction. Known control points (benchmarks) were established onshore using static GNSS observations. These benchmarks were used to validate positional accuracy and vertical referencing during the survey to ensure consistency in height values across the dataset. Figure 1 shows the map of the study area, while Plates 1-3 (figure 2) show part of the equipment deployed for the survey.

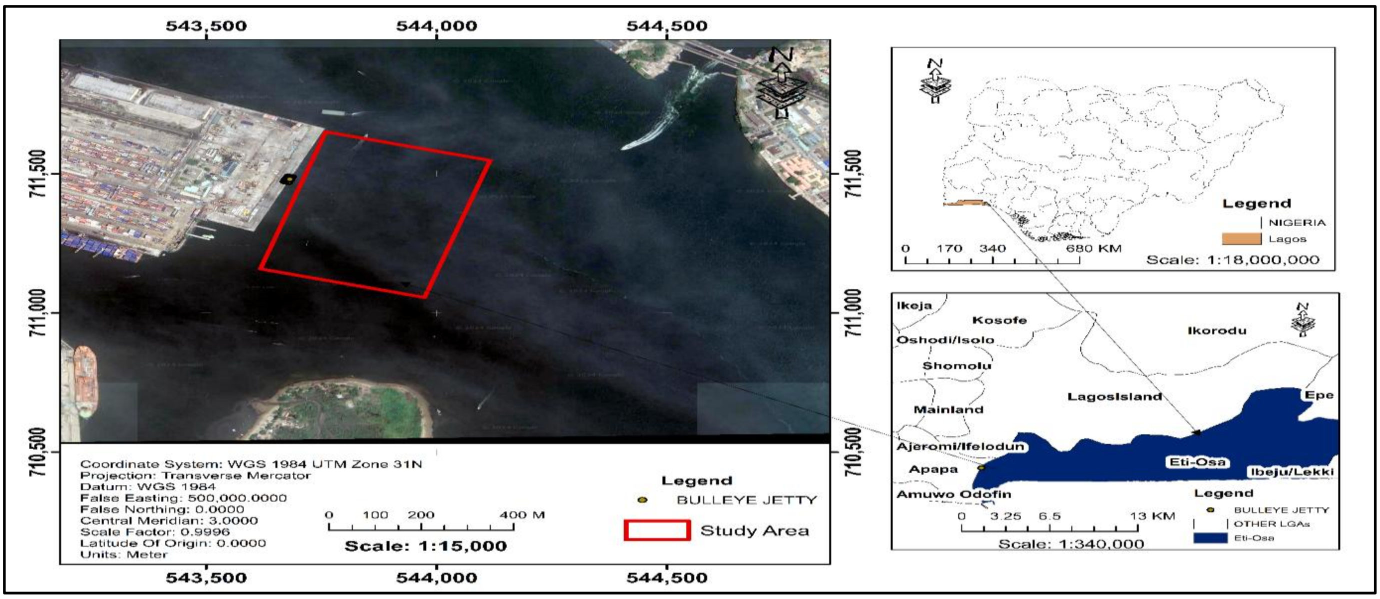

Figure 1. Map of the Study Area

Plate 1. The echo-sounder

Plate 2. The bathymetric survey equipment

Plate 3. Echo sounding operation on-going / probing of the proposed pile point

Figure 2. Part of the equipment deployed for the survey

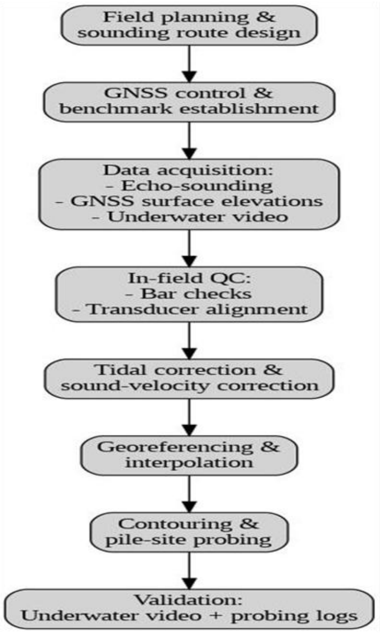

Figure 3. Flow diagram of the procedure

2.2. Positional Accuracy Using GNSS

For GNSS measurements, accuracy can typically be expressed in terms of horizontal and vertical positioning errors. We adopted equations 1-3 to present how positional accuracy [18]; [19]: Horizontal Positioning Error (HPE); Vertical Positioning Error (VPE); Coordinates Conversion from Spherical to Cartesian coordinates was validated and accomplished.

$$HEP = \left(\sqrt{(E_x)^2 + (N_x)^2}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where:
Ex = Error in the *x*-coordinate (longitude)
Nx = Error in the *y*-coordinate (latitude)
VPE = *Ez*

$$VPE = |h_T - h_M| = E_Z \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where:
h_T: True height (elevation).
h_M: Measured height by the GNSS receiver.
Ez = Error in the z-coordinate (elevation/height)

The measurements are initially in GNSS geographic coordinates (latitude ϕ, longitude λ), this was converted to a Cartesian system in the Earth-Centered Earth-Fixed (ECEF) system for detailed processing using equation 3 [20]; [21]. Assuming a spherical Earth (ideal conditions):

$$\left.\begin{aligned} X &= (N+h)\cos\phi\cos\lambda \\ Y &= (N+h)\cos\phi\sin\lambda \\ Z &= \left[(1-e^2)N + h\right]\sin\phi \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where:

$N = \dfrac{a}{\sqrt{1-e^2\sin^2\phi}}$: Radius of curvature in the prime vertical

a: Semi-major axis of the ellipsoid (WGS84=6,378,137 m)

$e^2 = \dfrac{a^2-b^2}{a^2}$: Eccentricity squared of the ellipsoid

b: Semi-minor axis of the ellipsoid

2.3 Grid Spacing and Area Calculation

The following approach, as presented in equations 4-5, was applied to plan for the grid-based traversing of the bathymetric survey transect lines at distance 0.1 m intervals [22].

$$TP = \left(\frac{L}{d}+1\right)\times\left(\frac{W}{d}+1\right) \ldots\ldots\ldots\ldots 4$$

Where:
TP: is the Total Points.
L: Length of the survey area.
W: Width of the survey area.

$$A = L \times W \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

Where:
A: is the area

2.4 Bathymetric Survey Procedure and Data Acquisition Processes

The bathymetric survey was conducted using a digital echo sounder (single beam) mounted on a stable survey vessel. The transducer was connected to a computer system for real-time monitoring and data logging. The vessel was powered by a 75-horsepower Yamaha outboard engine, which provided smooth and steady movement during data collection. The echo sounder system was powered using a 12-volt car battery, enhancing portability and operational flexibility in the field.

Before data acquisition, the echo sounder was calibrated using a bar check method, employing a graduated check plate at 1-metre intervals over a total depth of 5 meters. This in-field quality control ensured the accuracy and reliability of the depth measurements. Depth was determined by measuring the two-way travel time of the acoustic signal transmitted by the echo sounder and GNSS receiver fixes position relative to the surface elevation approach, based on the standard hydrographic sonar equation 6 [18]; [22], expressed as:

$$D = \frac{t \times v}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where:
D : is the depth
t :Two-way travel time of the acoustic signal (measured by the echo sounder), in seconds.
v :Speed of sound in water, typically around 1,500 m/s, but this value depends on water temperature, salinity, and pressure.
Therefore,

$$D = SE - MD \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

Where:
D : is the depth
SE : is the surface elevation, which is determined by GNSS measurements.
MD : is the measured depth

2.5 Quality control

Quality control carried out includes equipment calibration at the beginning and after the survey to ensure the equipment readings are consistent. Post-Processing is another important part of the QC. After data collection, post-processing techniques such as georeferencing and sound velocity corrections were applied to improve the quality and accuracy of the final dataset. Georeferencing ensures that positional discrepancies are corrected, while sound velocity corrections help refine the depth measurements based on accurate environmental data.

2.6 Data Processing and Post-Survey Analysis

Bathymetric and environmental data were processed in Surfer 16, beginning with the creation of gridded surfaces using Kriging interpolation, a statistical method ensuring high accuracy in depth representation. The Kriging model estimates depth at a point $z(x)$ based on weighted neighboring values following the geostatistical principles originally proposed by [21] and formalized by [22], as shown in Equation 8. This process helps to generate contour maps and 3D surfaces:

$$z(x) = \sum_{i=1}^{n} w_i z(x_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 8$$

Where:
w_i are the weights calculated to minimize estimation error, and $z(x_i)$ are known data values at neighboring points.

To further refine the data, Gaussian smoothing was applied using a Gaussian kernel function to reduce noise and enhance spatial continuity, following the principles outlined by [23]; [24], as presented in Equation 9:

$$G(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-x_0)^2}{2\sigma^2}} \quad \ldots 9$$

From equation 9, $G(x)$ is the weight assigned to a point x, x_o is the reference point, and σ is the standard deviation controlling the smoothness.
The smoothed value at a target point $y(x_0)$ was computed using the Gaussian-weighted averaging function shown in Equation 10, consistent with standard kernel smoothing approaches in spatial data analysis [24]; [25].

$$y(x_0) = \frac{\sum_i G(x_i - x_0) y(x_i)}{\sum_i G(x_i - x_0)} \quad \ldots\ldots\ldots\ldots\ldots\ldots 10$$

The refined surface was exported in DXF and TIN formats for compatibility with AutoCAD Civil 3D. In Civil 3D, the bathymetric data was reconstructed into a contour surface, and the design of the pile location was identified. The underwater investigation conducted at the Bullnose Jetty, Apapa, Lagos, yielded significant findings regarding the condition and stability of the piles within the repair section and surrounding areas. Observations from the survey provide insights into both the current state of the jetty's structural elements and the implications for ongoing repairs.

3. Results and Discussion

The results obtained through these research efforts are presented accordingly in the following sub-sections.

3.1 Bathymetric Profile and Measurement Uncertainties

The seabed across the surveyed area exhibited an undulating bathymetry with corrected depths ranging from 10.1 m to 13.2 m relative to local datum. Measurement uncertainty was quantified by calculating the standard deviation of repeated soundings on control transects and by combining instrumental vertical error (VPE ≈ ±0.03–0.08 m) with the uncertainty from tidal corrections (estimated ±0.05 m from tide logger variability). The combined expanded uncertainty (k=2) for corrected depths is estimated at approximately ±0.20 m, which is sufficient for engineering decisions on pile placement and obstruction avoidance. Figure 4 illustrates the overlay of bathy lines on the 2D plot of the sounding area, while Figure 5 shows the topographic profile. These results provided critical data for engineering designs while ensuring that seabed depths align with the operational requirements of the jetty. Variations in seabed depth can influence pile design and the overall stability of structures. These variations may be attributed to hydrodynamic forces such as tidal currents and vessel-induced turbulence, particularly near the quay edge. Such forces can cause sediment redistribution and scouring that affect structural integrity over time. Identifying deeper or irregular sections informs the strategic placement of piles to enhance structural integrity. When compared with similar surveys at the Benin River [3] and Badagry Creek [16], the Bullnose Jetty area exhibited more pronounced seabed variability. This may be due to heavier vessel traffic and structural influences on local sediment transport.

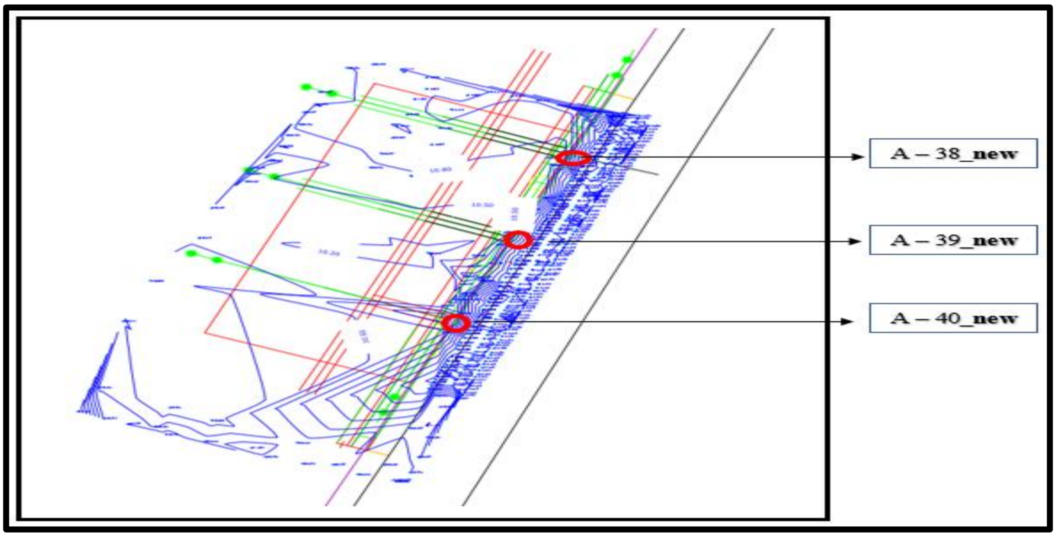

Figure 4. Overlay of 2D plot and bathymetric chart lines within observed area

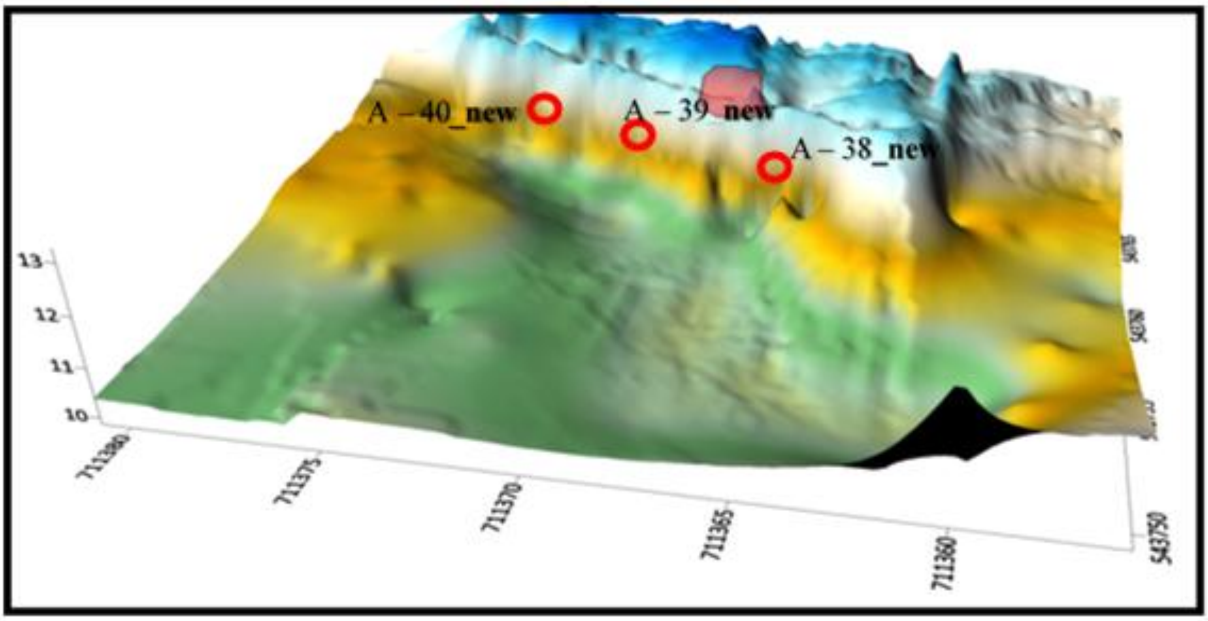

Figure 5. 3D surface map of underwater topography of investigated quayside

3.2 Vertical Alignment of New (P38_new, P39_new, P40_new)

The newly installed piles were inspected using underwater videography and bathymetric probing. No subsurface obstructions were detected beneath the new piles within the survey uncertainty envelope. These findings corroborate with prior pre-installation surveys in similar Lagos port settings carried out by [26], which reported comparable depth variability and the importance of high-resolution sounding for pile planning. The newly installed piles (P38_new, P39_new, P40_new) were observed to be vertically aligned and firmly driven into the seabed. Underwater video footage confirmed that there were no obstructions beneath these piles, affirming their stability and suitability. The absence of obstructions beneath newly installed piles also reflects the effectiveness of sediment clearance in zones prone to dynamic sedimentation. This confirms that proper pre-installation bathymetric probing mitigates risks of misalignment due to sediment buildup. Find attached photographs of the piles.

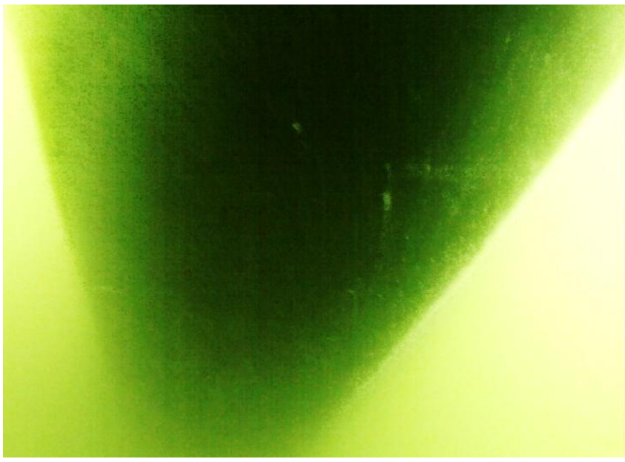

Plate 4: P38_new

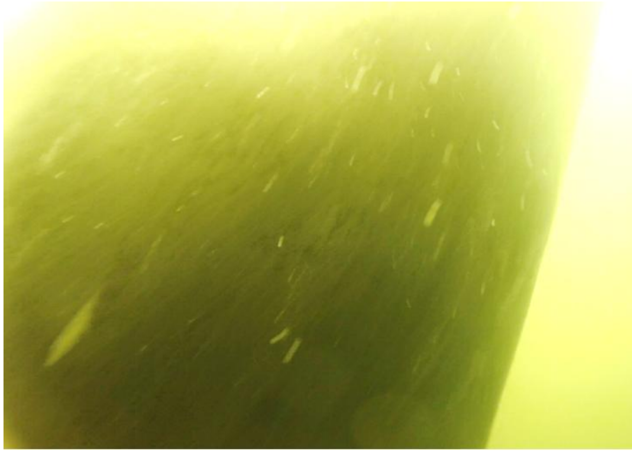

Plate 5: P39_new

Plate 6: Plate P40_new

Figure 6. Vertical alignment of new (P38_new, P39_new, P40_new)

As shown, it is clear that all the newly installed piles are firmly and truly vertical. As can be further confirmed from the videos, none of the newly installed piles is slanted. Furthermore, by checking them to the base, we observed that all the piles were driven through the earth, firmly into the seabed. Therefore, we conclude that the newly installed piles do not show any signs of obstruction beneath them. This is in line with the bathymetric probing conducted before the piling works, hence establishing the suitability of the piles and their positions.

3.3 Analysis of damaged piles and cause inference (P38A, P39A, P40A)

Visual evidence and bathymetric mapping show that pile P39A is broken and lying flat on the seabed in front of P38A. The fracture morphology and location suggest a sudden impact or overload event, consistent with collision or a concentrated lateral load followed by structural failure [17]. Localized seabed resistance around P38A noted during probing may have contributed to asymmetric loading during the incident. While a definitive mechanical failure analysis is beyond the scope of this survey, these observations recommend further structural assessment, such as material testing and finite-element analysis, if needed.

Plate 7. P38A: Broken in the middle by the impact of the accident

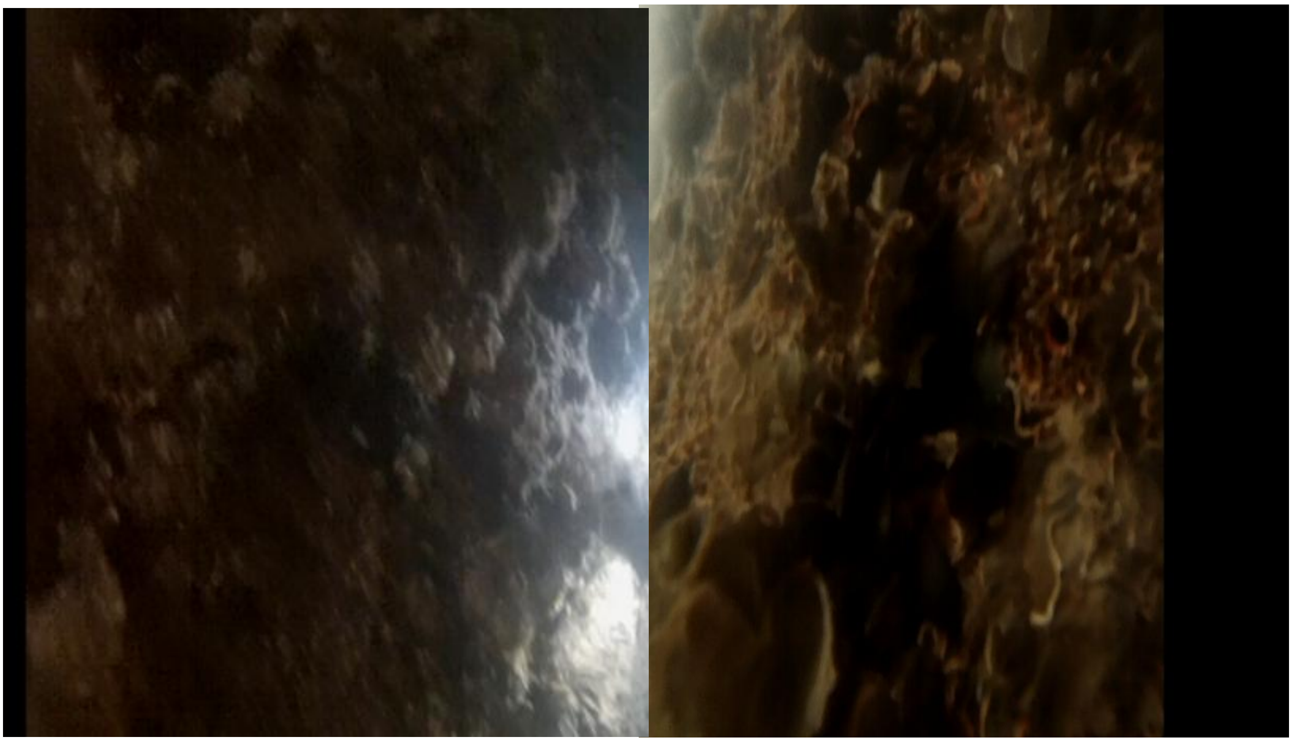

Plate 8. P40A: Fractured in the middle

Figure 7. Damaged piles and cause inference

3.4 Characteristics and Current Condition of Points of (P38B, P38C, P39B, P39C, P40B, and P40C)

Surrounding piles, including P38B, P38C, P39B, P39C, P40B, and P40C, were visually examined and found to be unaffected by the impacts. These piles maintained their structural integrity and vertical alignment, as confirmed by both photographic and physical inspections. This finding supports the localized nature of the damage and further reduces the concerns about potential widespread structural issues.

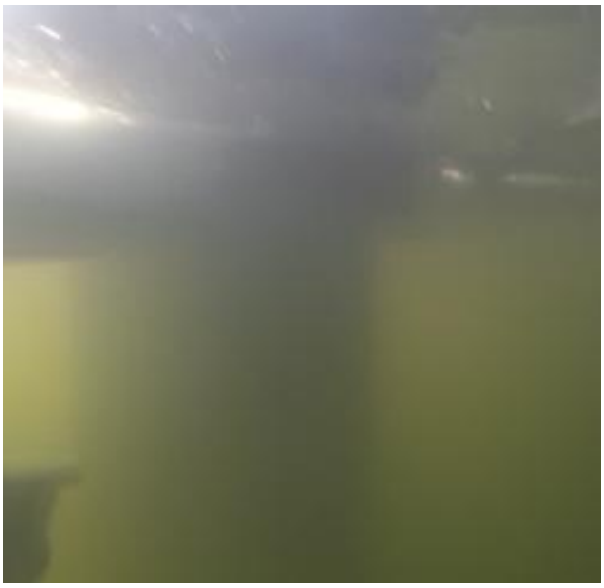

Plate 9. P38_B

Plate 10. P38C

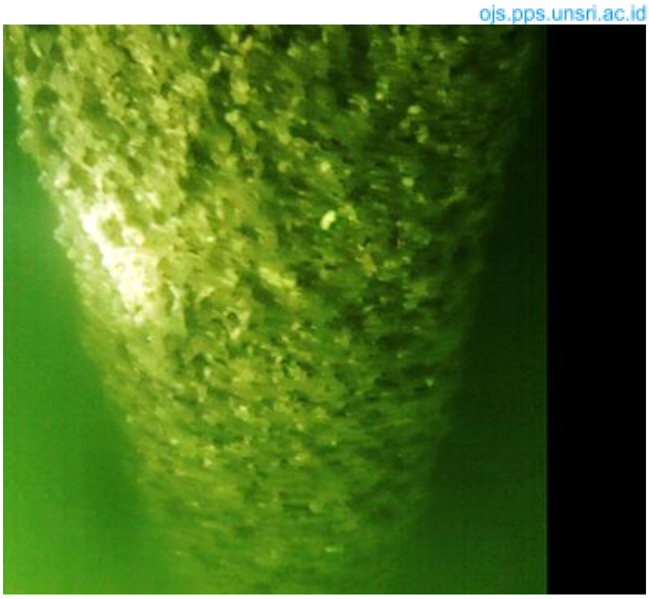

Plate 11: P39B

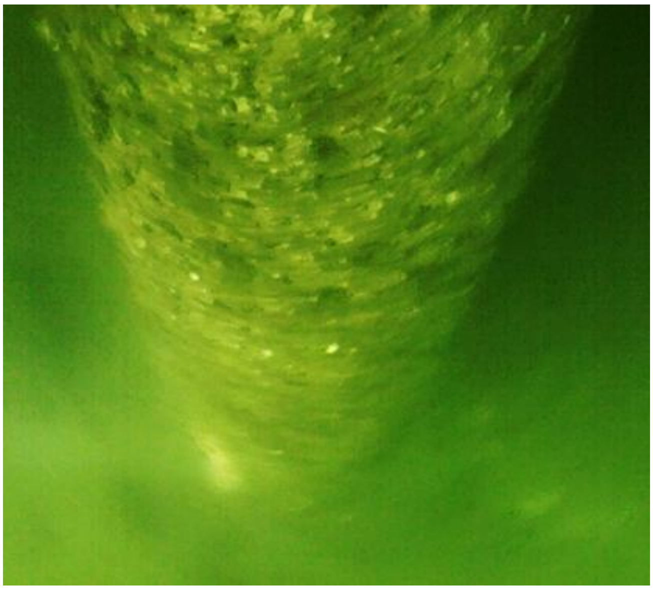

Plate 12. P39C

Plate 13. P40B

Plate 14. P40C

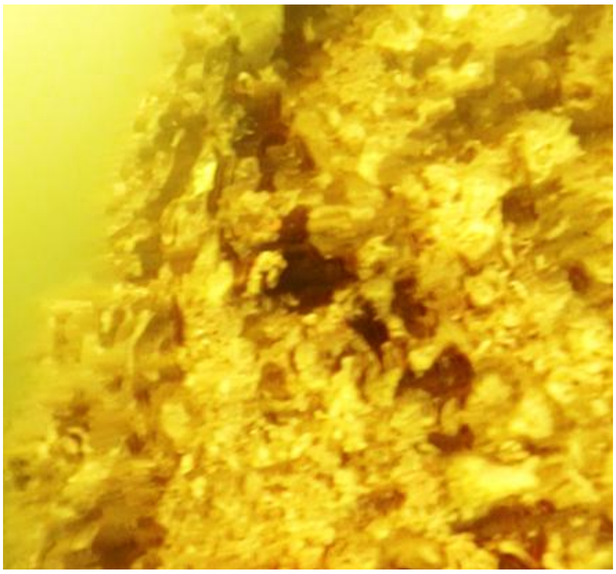

Plate 15. P50A

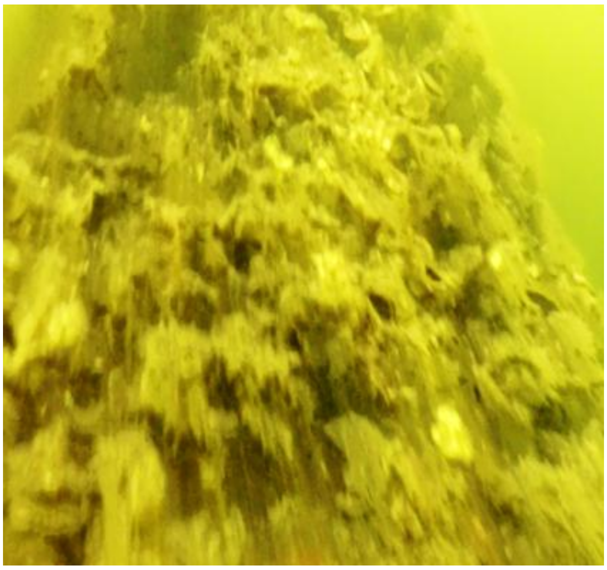

Plate 16. P58B

Figure 8. Characteristics and Current Condition of Points

Further examination was extended to piles outside the immediate repair area, specifically P50A and P58B. These piles were confirmed to align with the original design specifications, maintaining consistency with the newly installed piles. Photographs of P50A and P58B corroborate these observations, reinforcing the overall structural coherence of the jetty.

3.5 Location of broken pile (P39A)

The investigation also identified the location of the broken pile (P39A), which was found lying flat on the seabed in front of P38A. Its position dispels concerns regarding potential subsurface obstructions that might interfere with the new pile installation or vessel berthing operations. This discovery provides additional assurance about the safety and feasibility of ongoing repair activities.

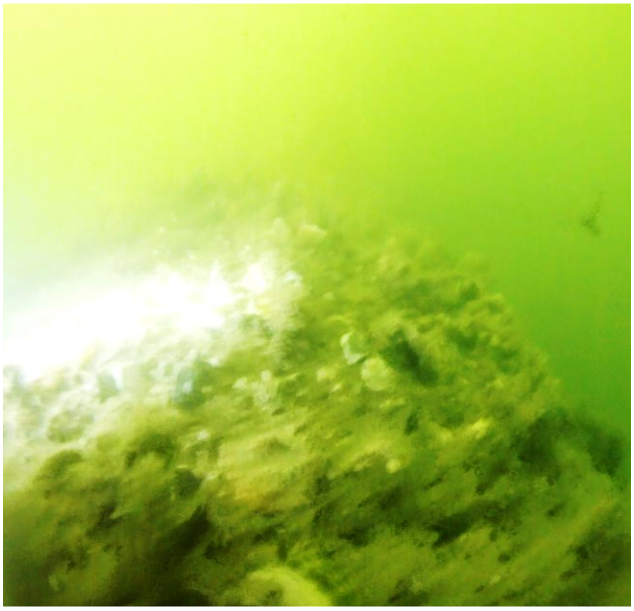

Plate 17. P39A

Figure 9. Location of the broken pile

The findings from this survey demonstrate the effectiveness of the repair work and provide actionable insights for future maintenance and monitoring efforts. The results emphasize the importance of rigorous pre-installation assessments and highlight the need for ongoing structural evaluations to ensure the jetty's long-term resilience.

4. Conclusions

This precision bathymetric and probing investigation at Bullnose Jetty provided high-resolution seabed mapping that directly supported piling and repair decision-making. Synthesizing the findings: (1) corrected depths across the area range between 10.1 m and 13.2 m, (2) proposed pile locations (A-38_new, A-39_new, A-40_new) exhibited no detectable obstructions within the survey uncertainty, and (3) the broken pile (P39A) was located lying flat on the seabed and poses no immediate subsurface obstruction to the new piles. These results demonstrate the value of paired GNSS-referenced echo-sounding and targeted probing for mitigation of operational risk during pile installation. Limitations of this study include the single-beam approach (which has lesser lateral coverage than multi-beam systems), the dependence on tidal corrections derived from a local tide logger, and potential temporal variability in seabed conditions. Future work should include periodic monitoring, multi-beam surveys to expand areal coverage, and structural analyses of damaged piles to better quantify the cause and long-term implications. We recommend that port authorities adopt routine, high-resolution bathymetric checks prior to major piling operations and implement a monitoring schedule that captures seasonal and storm-induced seabed changes.

Acknowledgement

The authors wish to appreciate Geosoft Solutions Limited: No 30, Montgomery Road, Sabo Yaba, Lagos State, for their role in providing equipment for data acquisition.

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