Analysis of bathymetric surfaces for the determination of sediments in the inner basin of the port of Salina Cruz, Oaxaca

Análisis de superficies batimétricas para la determinación de sedimentos en la dársena interior del puerto de Salina Cruz, Oaxaca

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Abstract

The Bathymetric Surface is original data from a bathymetric survey, or a cloud of points resulting from a subsequent edition keeping the associated metadata, can be processed based on a reticulated structure representing the geometry of the seabed as faithfully as possible, for a area of sea, river, lake or other navigable water, the primary objective of this work is to analyze the bathymetric surfaces derived from hydrographic surveys, to determine how the dragging of sediments has affected the depth in the inner dock of the port of Salina Cruz , Oaxaca. Due to the above, bathymetric data were obtained from the surveys carried out in the years 2010, 2018 and 2021 with the CEEDUCER PRO and R2 Sonic 2024 echosounder, the Hypack and CARIS BASE Editor programs were used for the management and validation of bathymetric data and to obtain the surfaces bathymetric at each time from the surveys and compare the interpolation models that generate the aforementioned surfaces derived from each survey. The results indicate that there are areas with greater sediment deposition where a depth ranging from 10 cm to 1.20 m has been lost according to the last bathymetry carried out in 2021, in order to provide safety conditions for navigation in the area of smaller vessels, tugboats, pilot vessels and vessels in general.

Bathymetric surfaces, Depth, Sedimentation

Resumen

La Superficie Batimétrica son datos originales de un levantamiento batimétrico, o una nube de puntos resultante de una edición posterior manteniendo los metadatos asociados, se pueden procesar en base a una estructura reticulada representando de la forma más fiel posible la geometría del fondo marino, para un área de mar, rio, lago u otra agua navegable, el objetivo primordial del presente trabajo es analizar las superficies batimétricas derivadas de los levantamientos hidrográficos, para determinar cómo ha afectado el arrastre de sedimentos a la profundidad en la dársena interior del puerto de Salina Cruz, Oaxaca. Por lo anterior se obtuvieron datos batimétricos de los levantamientos efectuados en los años 2010, 2018 y 2021 con la ecosonda CEEDUCER PRO y R2 Sonic 2024, se utilizaron los programas Hypack y CARIS BASE Editor para la gestión y validación de datos batimétricos y obtener las superficies batimétricas en cada época a partir de los levantamientos y comparar los modelos de interpolación que generan citadas superficies derivadas de cada levantamiento. Los resultados indican que existen zonas con mayor deposición de sedimentos donde se ha perdido una profundidad que va desde los 10 cm hasta el 1.20 m de acuerdo a la última batimetría realizada en el año 2021, a fin de proveer condiciones de seguridad para la navegación en el área de las embarcaciones menores, remolcadores, buques piloto y buques en general.

Superficies batimétricas, profundidad, sedimentación

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Introduction

Bathymetric surfaces consist of a set of grid values arranged to form a coverage representing a bathymetric depth model for an area of sea, river, lake or other navigable water. The data set includes both the estimated depth values and the uncertainty estimates associated with the depth values. That is, the dataset can carry both measured depth information that can be used for scientific purposes and corrected depth information that can be used for navigation (KHOA Korea Hydrographic and Oceanographic Agency, 2019).

Basile (2018) in his book "Sediment transport and morphodynamics of alluvial rivers" defines this concept as the granular solid material found in the bed of a river, basin, lake or coast which has been transported and deposited by the action of marine currents or other transport methods along its morphological evolution.

Silt is a deposit of sediment, which is carried by water and accumulated in riverbeds, dams, underground reservoirs, wetlands, lagoons, estuaries, navigation channels, harbours, etc., is called silt. The cause of siltation is a decrease in the velocity of the current and a corresponding decrease in the amount and size of solid material that can be carried in suspension. Thus, siltation is the phenomenon in which sediment accumulates and results in the transformation of the environment (Carbajal, 2014).

The equipment used for the hydrographic surveys included the CEEDUCER PRO single beam echo sounders and the R2 SONIC 2024 Multibeam Multibeam. The data acquired by means of this equipment provide a bathymetric surface with a resolution of even less than one metre, which results in a high-resolution configuration of the seabed.

The single-beam echo sounder is a type of electronic instrument that has a transducer that generates a single acoustic pulse (all the acoustic energy transmitted is confined to a single beam that has a cone-like shape) that reaches the seafloor, so it is not possible to obtain 100% coverage of the bottom, and it is necessary to make lines at a certain distance without being able to know what is between them (sectors without information) (Ballestero, 2010).

The use of multibeam echo sounders for bathymetry has become the most developed and accurate technology available today. This system, which complies with International Hydrographic Organisation (IHO) standards, provides accurate and complete knowledge of the depth and morphology of the seabed. This Multibeam system consists of a set of sounders that emit several narrow beams of sound in different directions, arranged in the shape of a fan that sweeps transversely in the direction in which the vessel is moving (Basile, 2018).

The port of Salina Cruz, Oaxaca, has a great relevance in the Mexican Pacific, as it is characterised by handling cargo traffic from the South (S) and Southeast (SE) region of the Mexican Republic, which includes the states of Oaxaca, Chiapas, Veracruz, Campeche, Tabasco, Puebla, among others. This port comprises the outer harbour, whose access is formed by two breakwaters and the dock, which communicates with the outer harbour through the channel called entrepuente (Administración Portuaria Integral, 2021).

Figure 1 shows the port's terminals and facilities, showing the inner manoeuvring dock with an approximate diameter of 300 m, where ship construction, repair and maintenance activities are carried out, as well as shipments of gas and refined products. In addition, work related to the fishing industry is carried out and the city's municipal waters are discharged.

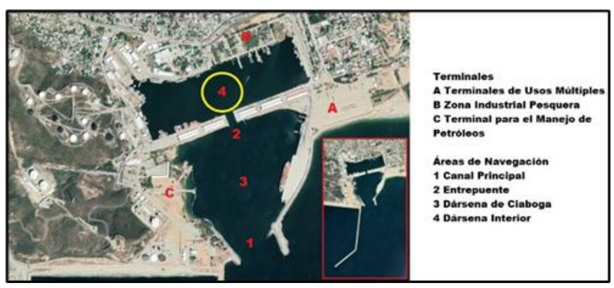

Figure 1 Port terminals and facilities
Source: Own elaboration

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Currently, the port of Salina Cruz, Oaxaca has a draught of 12 metres (m) in the navigation channel and 10 m in the inner dock, with 20.3 hectares (ha) for navigation. To date, the port has 14 berths for ships of greater draught, distributed in two terminals: a terminal for public use that handles bulk mineral, agricultural, containers and general cargo; and a terminal for private use, operated by Petróleos Mexicanos (PEMEX) for the storage and transport of petroleum fuels (Secretaria de Comunicaciones y Transportes, 2016).

This analysis focuses on the inner dock, shown in Figure 2, which is an area where vessels of more than 100 m. in length, up to smaller vessels that carry out the transfer of "pilot/practical" personnel that support the arrival of cargo ships, manoeuvre in and out of the port.

The Ministry of the Navy (SEMAR) has the ASTIMAR-20 where all ships entering for maintenance and repairs do so from the inner dock. Likewise, all the tugboats that provide support and push services to the larger vessels that arrive at the PEMEX terminal to load petroleum products are located in this basin.

Figure 2 Inner dock of the port of Salina Cruz, Oaxaca
Source: El Imparcial de Oaxaca, 2018

Methodology

This research was carried out by means of bathymetric data, acquired according to the established bottom coverage standards (IHO, 2008) in the inner harbour basin of the port of Salina Cruz during the years 2010, 2018 and 2021, with the R2 Sonic 2024 and CEEDUCER PRO multibeam echo sounders described in Table 1, which are presented in Figure 3. The R2Sonic 2024 and CEEDUCER PRO echo sounders have the following characteristics:

Characteristics Type	Echo sounders R2 SONIC 2024	CEEDUCER PRO
Frequency	Multibeam	Monohaz
Beamwidth across the scan	400 kHz/ 200 kHz	200 kHz / 30 khz
Number of beams	0.5 ° @400 kHz /1.0° @200 kHz	No scanning beam
Scanning angle	256	1 pulse per second
Pulse length	10° to 160° (user selectable)	Does not count
Pulse type	15µ Sec- 1000 µ Sec	Not specified
Depth range	Continuous waveform (CW)	1 pulse per second
Operating temperature	100 metres (3000 metres optional)	0.3- 99.9 m 0.75- 99.9 m
Storage temperature	-10°C to 40°C	0°C to 50°C
Characteristics	-30°C tp 55°C	Not specified

Table 1 System Specification of the R2 Sonic 2024 and CEEDUCER PRO echo sounders
Source: Operation manual R2 Sonic, 2024 and CEEDUCER PRO

Figure 3 shows the R2Sonic 2021 and CEEDUCER PRO echosounder and its modular interface.

Figure 3 Echosounder R2Sonic 2021 and CEEDUCER PRO and modular interface
Source: R2 Sonic 2024 and CEEDUCER PRO (2019) operation manual

Firstly, the Hypack 2021 programme in its version 1.21 was used to generate bathymetric surfaces for each epoch, and then, using one of the software tools called "TIN model" (Triangle Irregular Network), the data was processed to determine the sediment volume.

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The "TIN model" generates a type of vector-based digital geographic data that is constructed by triangulating a set of vertices (points). The vertices are connected with a series of edges to form a network of triangles. In other words, they connect three probes to make a triangular "face" (Figure 4). The faces can then be used to represent a bathymetric surface detailing volumes created from these triangles.

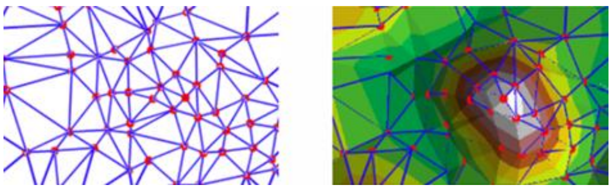

Figure 4 Creation of TIN models
Source: Hypack (2021)

The result after the creation of the TIN model (Figure 5), is the comparison between two accurately overlapping bathymetric surfaces, generating a report which, from the network of triangles, determines the volume of sedimentation added and removed, in this case in the interior of the manoeuvring basin of the port of Salina Cruz, Oaxaca.

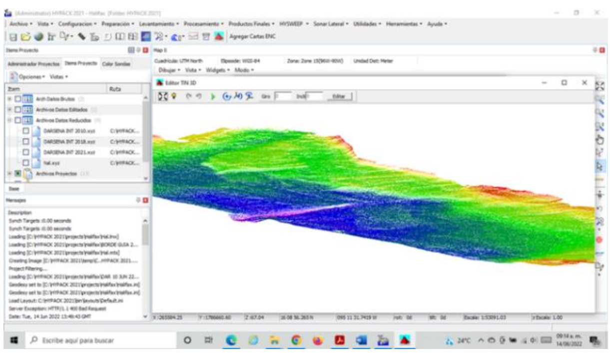

Figure 5 TIN model, from the bathymetric surfaces
Source: Hypack (2021)

On the other hand, with the CARIS Base Editor program, the bathymetric surfaces were generated from the same sounding data with which the TIN models were made in Hypack, in order to maintain the same information used and to serve as a point of comparison.

The bathymetric surfaces were generated through "XYZ" files (Figure 6), which contain the information on coordinates and depths, using the WGS84 reference datum.

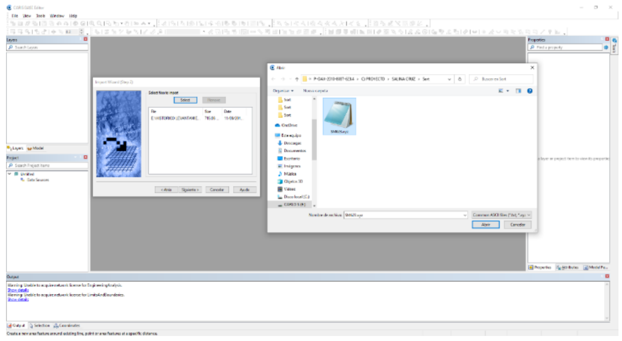

Figure 6 Import of bathymetric data from the XYZ file.
Source: CARIS Base Editor

The subsequent result was a bathymetric surface in two and three dimensions (Figure 7) for each year (2010, 2018 and 2021), where details of the seabed can be observed, distributed uniformly and by colour, in order to obtain a clear idea of the configuration of the area in question.

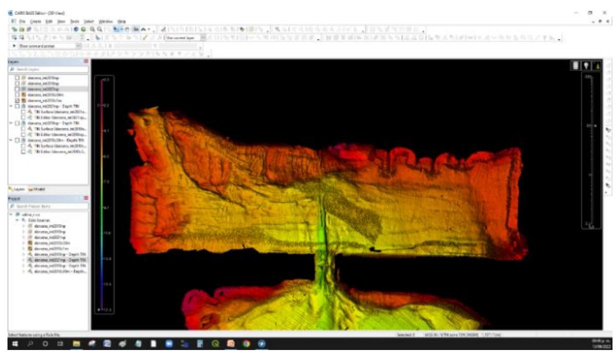

Figure 7 Bathymetric surface of the year 2010.
Source: CARIS Base Editor

Once the bathymetric surfaces for each year have been generated, the CARIS Base Editor program has a tool called "coverage difference" which, by interpolating two surfaces, generates a third one, which is the result of the difference between the two.

Results

The TIN models, described in the methodology of this article, generated from the data processed in Hypack, were merged, using the tool "TIN models", generating a report for the comparison of the bathymetric surfaces 2010 - 2018 (Figure 8) and 2018 - 2021 (Figure 9).

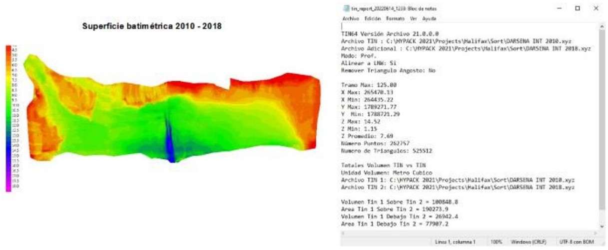

Figure 8 2010 - 2018 bathymetric surface and sediment report
Source: Hypack, (2021)

On the left of Figure 8 is the two-dimensional bathymetric surface generated from the interpolation of the 2010 and 2018 bathymetric surfaces, showing the soundings obtained during the 2010 and 2018 surveys, overlaid on top of one another. The depth scale shows the shallowest soundings from 4 m to the deepest areas at 18 m, which are located in the centre of the basin (coloured in blue), which belongs to the access channel and the passage from the interchange to the outer basin.

On the right side of Figure 8 is the report that generated the comparison of the bathymetric surfaces indicating that 525,512 triangles were generated from the existing sounding points, volume TIN 1 over TIN 2 indicates the amount of 100, 848.8 m3 that represents the matter that has been removed, while volume TIN 1 under TIN 2 indicates the amount of 26, 924.4 m3 that represents the matter that has been added, i.e. the sediments deposited during that period.

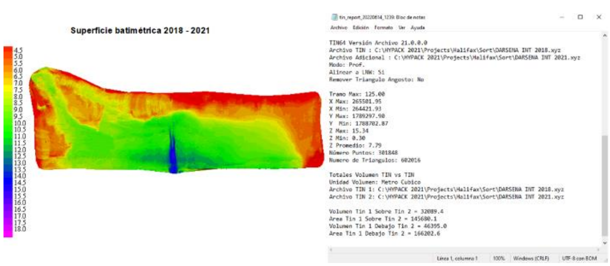

Figure 9 Bathymetric surface 2018 - 2021 and sediment report
Source: Hypack, (2021)

On the left hand side of Figure 9, the bathymetric surface derived from the 2018 - 2021 comparative, it shows a greater red colouring, which represents shallow depths, most noticeably in the area adjacent to the docks and the entrance to ASTIMAR-20.

This trend is reflected in the report generated by Hypack, which we can see on the right of Figure 9, which tells us that 602,016 triangles were generated from the existing sounding points, the volume TIN 1 above TIN 2 indicates the amount of 32,089.4 m3 which represents the material that has been removed, while the volume TIN 1 below TIN 2 indicates the amount of 46,395 m3, which corresponds to the material that has been added.

As part of the work carried out in the CARIS Base Editor program, bathymetric surfaces were generated for the years 2010 and 2018 (Figure 10).

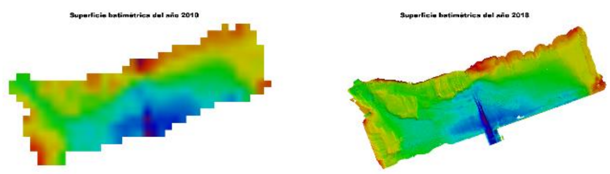

Figure 10 Bathymetric surfaces for the years 2010 and 2018
Source: CARIS Base Editor

Once the bathymetric surfaces for the years 2010 and 2018 were obtained, by means of the methodology described above, a third bathymetric surface was generated, which corresponds to the difference in depths found between each one, as shown in Figure 11.

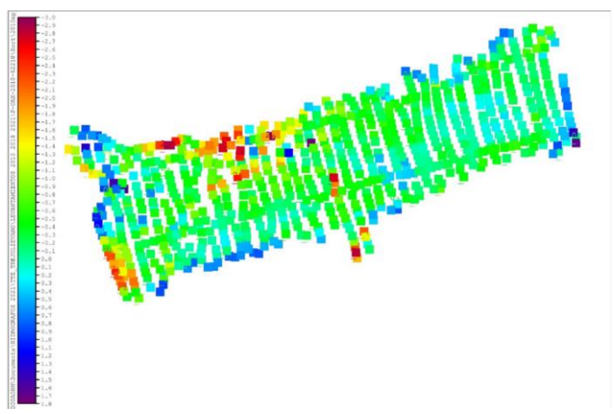

Figure 11 Difference in depths between the years 2010 and 2018
Source: CARIS Base Editor

The blue colour represents an average of 0.5 metres of depth that has been lost over the years, which is noticeable in clustered areas, which supports that the amount of 26, 924.4 m3 reported by the Hypack programme as deposited matter, is almost uniformly dispersed along the basin, showing areas with a higher concentration of sediment.

The bathymetric surfaces for the years 2018 and 2021 (Figure 12), also generated in CARIS Base Editor, are presented below. These surfaces have a higher resolution as both were obtained from data acquired with the R2 Sonic 2024 echosounder.

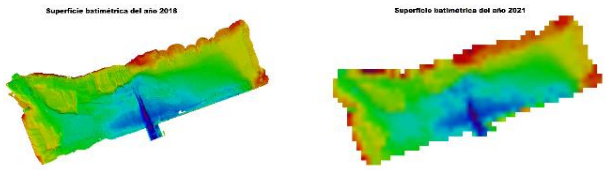

Figure 12 Bathymetric surfaces for the years 2018 and 2021
Source: CARIS Base Editor

In the same way, the bathymetric surfaces of the years 2018 and 2021 were interpolated, thus generating a third bathymetric surface, which corresponds to the difference in depths between the years 2018 and 2021 shown in Figure 13.

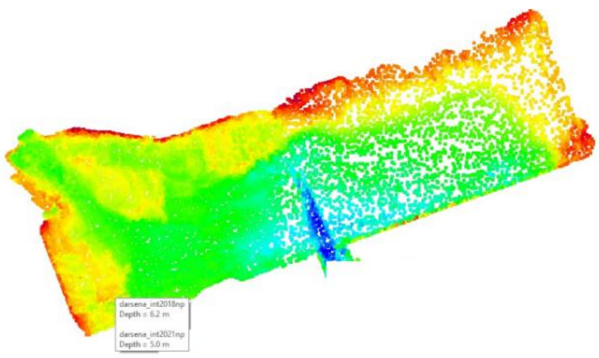

Figure 13 Difference in depths between years 2018 and 2021
Source: CARIS Base Editor

This bathymetric surface shows one of the most representative areas where depth has been lost, as in 2018 there were 6.2 metres, compared to 2021 where soundings of 5.0 metres are recorded, strictly speaking, there are areas where the depth has decreased to 1. 2 meters, corresponding to this surface, according to the report generated by Hypack the amount of 46,395 m3 of matter that has been deposited, observing a tendency of concentration in the vicinity of the docks, and not so in the centre of the dock.

Based on the above, and with the CARIS Base Editor program, a 3-D view (X10 exaggeration) of the seabed (Figure 14) was obtained for the year 2021, in order to observe the configuration of the seabed and to determine the areas most vulnerable to sedimentation.

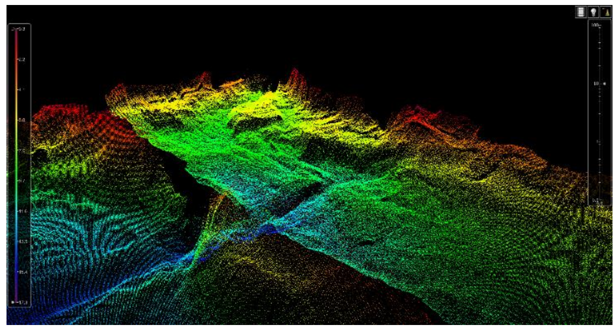

Figure 14 Seabed in the inner harbour in the year 2021
Source: CARIS Base Editor

Areas in yellow and red can be clearly seen, which belong to the vicinity of the dock, where there are submarine mounds, which due to their characteristics are difficult to remove by dredging, being therefore places where, with the passage of time, sedimentation adheres and leads to the loss of depth and therefore a danger to navigation, but especially for ships with drafts greater than 3 metres.

Conclusions

By means of the Hypack and CARIS Base Editor programs, the bathymetric surfaces were analysed, obtaining the volume of sediment (added and removed material) by means of Hypack and TIN models, while by means of the CARIS Base Editor program, the difference in depths was obtained for each model, being represented in two and three dimensions, thus locating the most vulnerable areas, where sedimentation has not been removed and causes a loss of depth.

It was verified that it is possible to determine the volume of sediments, from the analysis of bathymetric surfaces in Hypack, using the CARIS Base Editor program as a method of help and verification, thus determining that the areas where there is a greater loss of depth are those near the docks and the entrance to the Navy Yard No. 20.

Recommendations

Dredging should be carried out in the inner dock of the port of Salina Cruz, on a constant and permanent basis, being recommended at least once a year. Likewise, and prior to works of this nature, it is proposed that a soil mechanics study be carried out, aimed at the foundations of the dock, in order to determine the scour generated by the fluid dynamics, so as to be certain that dredging can be carried out in the vicinity of the docks or that modernisation or reinforcement of structures is necessary.

The port of Salina Cruz, Oaxaca, is no stranger to the problem of siltation and sediment transport, according to Carmona (2006) in the study he carried out in the area, entitled "Application of civil engineering to the problem of beach erosion in the region of La Ventosa Bay in Salina Cruz, Oaxaca", in which he writes how the coastal area near the port has suffered a decrease in depth due to the breaking of waves near the beach line and breakwaters, which causes turbulence in the flow and consequently the suspension and dragging of granular material.

Derived from the above, the inner harbour of the port of Salina Cruz also presents a dragging of sediments that, due to different causes, such as runoff and turbulence in the flow of currents, generate silt and sedimentation, being the main problem that causes the loss of depth. Another important factor is the estuaries present in the area, which are located between the rivers and the coasts and act as material traps, causing a deficit in the beach area, which is why it was necessary to analyse the bathymetries carried out in the inner dock for the years 2010, 2018 and 2021. The most significant variables for the study were depth and sediments. The Hypack and CARIS BASE Editor programmes were used to process them, in order to achieve the objective of analysing the bathymetric surfaces for the determination of sediments in the inner basin, with the aim of providing greater safety and confidence to the navigators who use the port (Carmona, 2006).

Likewise, the Administración Portuaria Integral (API) in its report "Manifestación de impacto ambiental modalidad regional para la modernización del puerto petrolero y comercial del puerto de Salina Cruz, Oaxaca (2021)" describes the importance of carrying out a dredging project, due to the need to increase the depth in the oil and commercial area to allow the arrival of larger vessels, as the depths of the navigation channel and manoeuvring basin are not adequate.

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