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Study the Effect of Measured Heave in Single Beam Hydrographic Survey on Dredged Quantity Estimation

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Abstract

Dredge quantity estimation is a critical issue in dredging projects as it has direct impact on the project process and cost. Hydrographic survey is the main tool for measuring the horizontal coordinates and vertical levels of the sea bed and subsequently quantity estimation. Heave is one of the factors that did not mentioned by "IHO Standards for Hydrographic Survey, (2008)" to be measured in its specifications. They only mentioned that for Sweep Systems (multi-transducers arrays): "Once the heave on the transducers exceeds the maximum allowable value in the uncertainty budget, sounding operations should be discontinued until sea conditions improve".

In dredging works, some consultants insisted to use at least heave motion sensor in doing the bathymetric survey works especially for harbors dredging works in spite of the survey works will cover all aspects of IHO special order and/or order "A" classes. No previous study was done to see how the effect of Heave on the estimated dredged quantities. The current study investigates the impacts of heave on the computed dredged quantities in harbors in Damitta Port, Egypt, and the new Bobyian Seaport in Kuwait for maintenance and capital dredging works.

Keywords: Dredging works, Hydrographic Survey, Heave

1. Introduction

Hydrographic surveying, techniques and equipments, is the only tool that can enable the designer to prepare the topo-mapping of the seabed. Hydrographic surveying deals with the configuration of the bottom and adjacent land areas of oceans, lakes, rivers, harbors, and other water forms on Earth. In strict sense, it is defined merely as the surveying of a water area. Most marine projects require some degree of hydrographic surveying during each stage of a project's life, i.e., planning, acquisition, design, construction, operation, and maintenance. The principal objective of most hydrographic surveys is to obtain basic data for the compilation of nautical charts with emphasis on the features that may affect safe navigation. Other objectives include acquiring the information necessary for related marine navigational products and for coastal zone management, engineering, and science **(FIG Publication No. 56, (2010)**).

The port surveys are done to ensure that the waterways are free from obstructions and the depth is sufficient for safe shipping. The potential dangers to shipping in waters are inadequately surveyed and charted. Shipping casualties can result in loss of life and severe (and costly) damage to vessels. Shipping safety depends not only on component navigation but adequate hydrography and up-to-date charts. Dredging and underwater excavation are an important aspects in the design and construction of certain key elements of a harbor's infrastructure. The basic requirements to assess dredging works are an accurate estimate of the volumes to be excavated or dredged and an accurate evaluation of the nature of the material to be excavated. Accurate volume estimate is an important for the choice of dredging plant, production estimates, times of execution and ultimately project costs. Expressed in quantities, a dredging operation can extend from a few hundred cubic meters to many millions of cubic meters **(A. El-Hattab, 2014).**

Hydrographic surveys are always employed for estimation of dredging requirements, determine dredging contractor payment, monitoring the offshore disposal areas and to certify final acceptance and clearance of a project to its authorized navigation depth. The widely accepted method for obtaining depths data is with a single-beam echo sounder (SBES), with position provided by Global Positioning System (GPS), particularly in differential (DGPS) and real time kinematic (RTK) modes. The RTK mode can be used to determine the height of the boat from which soundings are taken and the required order of survey precision can be met. Use of the water surface as the reference for reduction of soundings is no longer necessary. Real time measurement of the height of the boat also removes the need to **(M. Rabah (2009)**:

- Measure tidal height, including making any allowance for the time and range difference between the tide at the recording station and at the survey site
- Measure heave (vertical rise and fall of the vessel due to swell and wave action)
- Squat (vertical rise or fall of the vessel due to changing hydrostatic pressure around the hull as the boat moves through the water)
- Measure vessel motion along multiple axes, RTK GPS receiver with a minimum of three antennas is needed. Various authors have discussed the measurement of vessel motion using GPS;

The GPS antenna and the transducer were in the same plumb line; the data collected between RTK GPS and transducer were simultaneous strictly because only in this way, the positioning data and the depth will be coincident. We checked point for the bathymetric survey through comparing the coordinates of a reference point and the measured values by the RTK GPS of the survey boat before starting the survey every day.

Hydrographic surveying uncertainties can have important consequences for a project, especially when operations involve stone placement where uncertainties are more liable to take place. The cost of the dredging work can be also affected due to inaccurate estimated volume of dredged quantities. The demand for greater transparency in the derived accuracy of soundings taken in swell conditions has seen the use of motion sensor equipment become standard in an increasing number of port and harbor surveys (**FIG Publication No. 56 (2010)**).

The current study investigates the effect of measured heave of single beam hydrographic survey on the calculated volumes of the dredged materials. This will be done after introducing the effects of heave on the measured depths and vertical position.

2. Heave Measurements

Heave is the vertical translation of the vessel relative to the average water level. Heave sensors typically utilize double integration of vertical acceleration, followed up with a high-pass filtering operation. Several approaches have been considered for measuring heave-induced errors in hydrographic survey, depth measurements. Heave motion of a survey vessel has traditionally been measured using inertial technologies, which can be expensive and have problems with usability and instability, resulting in higher survey costs and a significant hydrographer input burden. The survey boat attitude can be measured using several types of instruments. These instruments measurement systems can be grouped into the following general categories (**Perwick, M. (2000)**): (1) pendulum systems, (2) gyroscope systems, (3) accelerometer systems and (4) combination systems.

Most survey vessels now are equipped with some type of motion compensation instrument. The accelerometer is the standard type of motion sensor equipment, and different units range in their complexity, and in the precision they are capable of achieving. These instruments are generally referred to as "motion reference units," or MRUs. This instrumentation provides correction for vessel roll, pitch, yaw, and/or heave. The type, complexity, and cost of this equipment are dependent on the typical sea states encountered and specified data quality requirements for the survey. On shallow draft inland projects, motion compensation may not be required for single beam surveys. Motion compensation systems can exceed the cost of an acoustic depth measurement system. High-end (accurate) inertial-aided GPS motion systems can cost up to $200,000. Basic motion compensation systems are less than $50,000. Project engineers specifying survey requirements should be cognizant of their district's survey capabilities, and whether the lack of motion sensing equipment will adversely affect the resultant data quality.

Kinematic GPS is becoming increasingly popular as an alternative method of correcting vessel motion, either in conjunction with, or in lieu of, accelerometer-based motion sensors. While providing a low cost alternative for measuring roll, pitch and heading, the update rate of the GPS (typically 10Hz) limits its ability to serve as an accurate heave measurement sensor. Thus, users of both types of motion sensors should take all practical steps to check their correct operation, preferably by some means of ground-truthing (e.g. quantifying the motion error residual in data collected over a known flat seabed) (**FIG Publication No. 56 (2010)**)..

In theory, heave is not necessary because vertical movement experienced by the antenna is included in the vertical transducer movement. A single observation of the antenna location combined with a depth observation at the same epoch (adding the pitch and roll corrected antenna/transducer offset) will produce a depth from the ellipsoid to the sea bed. However, GNSS and depth observations are rarely collected at the same rate, with depth observations collected at a rate determined by water depth and therefore requiring interpolation. Also, the GNSS rate is usually not high enough to capture the entire heave signal (although that is changing). Because heave sensor measurements occur at a much higher frequency (>> 20 Hz) than GNSS (< 10 Hz), they are useful for the interpolation of vertical movement between GNSS height records, see figure (1). Although high-accuracy GNSS may reduce the reliance on heave sensor observations, best practices should dictate inclusion of these observations for redundancy, interpolation and GNSS observation validation. Inertial-aided GNSS positioning, which couples high-rate IMU data to the GNSS measurements, provides a smoothed height with high enough resolution to allow for direct combination with the depths (**M. Rabah and A. El-Hattab (2010).**

For hydrographic survey applications the use of observed heave in combination with GNSS heights can be confusing. There are essentially two methods of dealing with heave: One is to apply observed heave to depths and then remove the observed heave from the GNSS height observations. The other is a direct observation from the ellipsoid to the seabed, ignoring heave as a distinct entity. In many cases heave is applied to depths in real-time, and must then be removed from the GNSS height observations. In this case the heave-corrected GNSS heights can be used as pseudo-tide observations, and can be smoothed to remove noise from the vertical GNSS position. The term pseudo-tide is used here because the smoothed water level will still include dynamic draft and other low-frequency variations or artifacts in the vertical offset. In order to obtain corrected data during acquisition, the application of heave is necessary; however, the heave component is no longer as essential (and problematic) a component as it once was.

3. Dredge Volume Computation Techniques

Volume estimation is a critical issue in dredging because it has direct impact on the cost of the project. To calculate the volume of dredged quantities, hydrographic surveying and volume calculation models have to be employed. Dredge surveys can be split into three groups: pre-dredge, progress or interim, and post-dredge surveys. Pre-dredge surveys are performed before starting dredge works and are considered the initial survey data. For monthly payments, progress surveys are conducted to estimate the dredged volume. A post-dredge survey is accomplished after dredging has been completed in a specific location to ensure that all materials have been removed and the required depths are reached. Many methods can be applied for dredged volume estimation. Most of these methods depend on area of cross sections, triangulated irregular network, and regular grids based on digital elevation models. Each method has its individual characteristics, applicable conditions, and different levels of uncertainty **(US Army Corps of Engineers (1994)).**

Dredge volume computation procedures have generally followed those used in railroad and roadway construction the Average End Area (AEA) method. Cross-sections of a channel are taken at a constant interval and the quantity is computed based on the volume between the cross-sections. The major assumption is that the cross-sectional area is relatively constant between two successive cross-sections. If not, then this method becomes an approximation (or estimate) of the true volume. Decreasing cross-sectional spacing to improve the AEA computation accuracy had economic limits due to increased field survey costs. Thus, cross-sectional spacing for most dredging work ranged from 25m to 100m. Alternate computational methods have been used to compute volumes of sparse cross-sectional data. These include the Prismoidal correction to the AEA method and the Triangulated Irregular Network (TIN) method.

In general, all commonly used volume computation methods reduce down to that of determining the area bounded by a finite group of data points and projecting this area over some length to obtain a prismoidal volume. These projections may be done either horizontally or vertically, as shown in figure (1). The volume computation used methods are:

- Average End Area --used for sparse cross-section data
- Triangulated Irregular Network-- used for sparse cross-section data

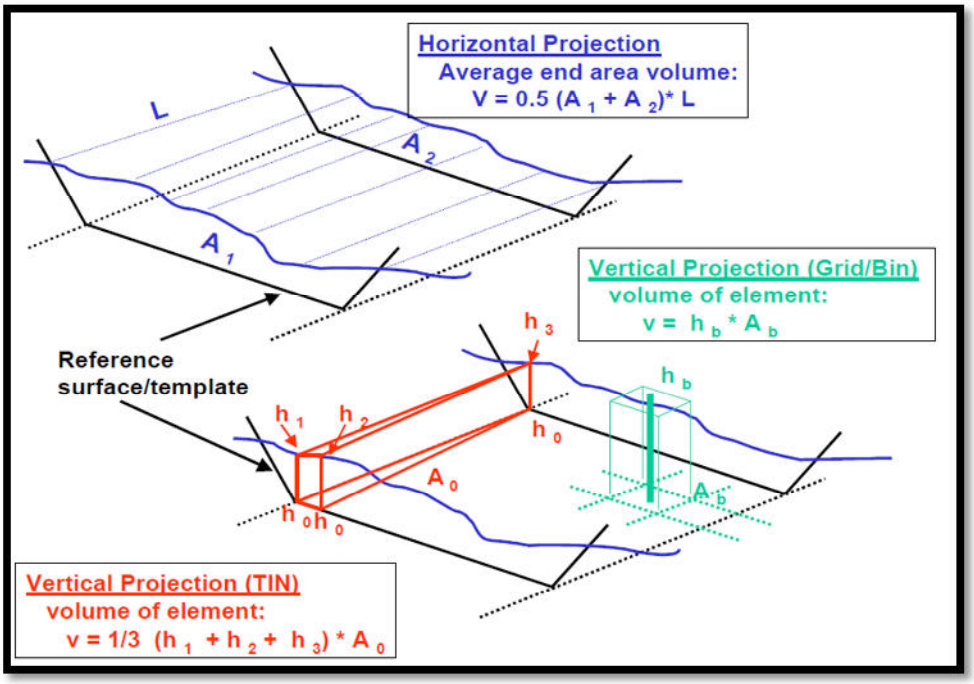

Figure (1): Generalized depiction of Average End Area, TIN, and binned volume computation methods

3.1 Average-End-Area Volume

For most construction and dredging work, the horizontally-projected average end area (AEA) method has been considered the standard volume computation method when sparse cross-section data is available (i.e, 25 to 150 m spaced cross-sections). An alternate method is to develop vertical prismoidal elements between the sparse cross-sectional data, and compute the volume of each prismoidal element--a vertical projection, see figure (1). Development of the triangular prisms between two cross-sections is termed a Triangulated Irregular Network, or "TIN." TINs have application when data are sparse, such as is typical in widely spaced cross-sections, and where cross-line data is available. When full-coverage data is available from multiple transducer or multibeam systems, it can be gridded or binned at dense grid spacing, and volumes computed from the vertical projection of each grid cell to a reference surface.

3.2 Triangulation-Based Volume Computations (Triangulated Irregular Networks)

The Triangulated Irregular Network (TIN) volume technique is based on comparison of two terrain models. In the case of dredged material volumes, one model represents the actual bottom terrain as surveyed, and the other model usually represents a design surface (e.g., required depth and over-depth), although two surveyed surfaces can also be compared. TIN routines offer great flexibility in the collection of survey data, since the terrain coordinates need not be in any particular pattern or alignment. TIN programs also enable visual terrain models of the surveyed topography and of design, or hypothetical, terrain surfaces see figure (1). The TIN model volume is also more accurate than an AEA volume computed from the same data base. TIN routines for volume determination and terrain visualization are commonly available in commercial site design and some survey software packages. For dredged material volume applications, TIN routines are particularly well-suited to cases in which the channel is not a simple straight layout, such as in turning basins, settling basins, widener sections, curved channels, etc.

4. Survey Specifications

To accommodate hydrographic surveys in a systematic manner, different accuracy requirements for areas to be surveyed, four orders of survey are defined by IHO and described in Table (1) **(IHO, Publication S-44 5th Edition 2008)**. Although there are numerous country-defined designations of allowable tolerances for vertical control during hydrographic surveys, the IHO has developed a set of standards that have been adopted by many member countries. Table (1) summarizes the overall requirements but should be read in conjunction with the complete standard as well as it gives the position tolerances as a function of survey order. The depth accuracies include all errors in positioning and propagation. We can roughly equate the fixed ‘a’ value for each order to the allowable positioning error.

Table (1): International Hydrographic Organization positioning standards (IHO, 2008)

Order	Special	1a	1b	2
Area Example	Areas where under-keel clearance is critical	Areas shallower than 100 m where under-keel clearance is less critical but features of concern to surface shipping may exist.	Areas shallower than 100mwhere under-keel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas generally deeper than 100 m where a general description of the sea floor is Considered adequate.
Maximum allowable THU 95% Confidence level	2m	5m+ 5% depth	5m+ 5% depth	20m+ 10% depth
Maximum allowable TVU 95% Confidence level	a=0.25m b=0.0075	a = 0.5 m b = 0.013	a = 0.5 m b = 0.013	a = 1.0 m b = 0.023
Where depth accuracy is given as:		$\pm\sqrt{a^2 + (b * depth)^2}$		

5. Study the Heave Effect on the Computed Dredging Quantities

To study the effect of heave on the computed dredging quantities, two tests were performed. The first test was done for routine dredging works across a harbor where a single beam survey was done perpendicular to the center line of the navigational channel. The second test was executed along in open sea, along a virtual channel; with single beam survey parallel to the center line and extended for several tens of km.

In the following subchapter, a description of the first hydrographic survey test along Damietta Port is given. The main components and parameters of the performed hydrographic survey across Damietta Port are discussed. A heave study was done based on two assumptions:

- The first assumption is done based on normal routine maintenance dredging works for Damietta Port where the dredged quantities are computed based on the existing of heave correction and non existing heave.
- The second assumption is done based on capital dredging works, i.e. increasing the chart depths of Damietta Port from 14.5m to 16.0m. The dredged quantities are computed based on the existing of heave correction and non existing heave.

5.1 The First Test: Hydrographic Survey across Damietta Port

Damietta port is considered one of the oldest ports in Egypt since pharaohs' time. Damietta port has been established to take off load on Egyptian ports, and studies and executive works for such a giant project have started and the project has become a reality and was inaugurated in 1986 and has become since then the most important port East the Mediterranean. Damietta Port is located Latitude 31^o 23' N and Longitude 31 ^{o} 48' situated at 10.5 km west of the Nile river of Damietta branch westward Ras El-Bar, and it is 70 km away from Port Said and 200 Km from Alex. Port. The port installations extend on an area of 11.8 km2. The port is bordered by an imaginary line connecting the eastern and western external breakwaters, see figure (2).

Damietta port has an Entrance Channel of length 11.4 km. long, 15 m. deep, and 300 m. wide gradually decreasing to reach 250 m. at the breakwater fringe. The canal is surrounded by 18 buoys which are lit at night, odd numbers on the right and even numbers on the left, There is an external waiting area. The port has two breakwaters. The western breakwater is 1640 m. long with 140 m. land-based and 1500 m. sea-based area. The eastern breakwater is 750 m. long with 200 m. land-based and 550m sea-based area. Both breakwaters are made of stacked artificial acrobod piles topped with a concrete head. Both breakwaters are protected from the external side the industrial acrid bocks and they are topped by a cement layer.

5.1.1 Density of Data and Line Spacing

The density of bathymetric data collected is determined by a number of project-dependent factors. Some of the considerations that are used to determine the required data density and the survey, etc. and related site investigation requirements:

- Survey data collection equipment (lead line, analog echo sounder, multiple-array acoustic sweep system, automated data collection, etc.) capabilities and limitations.

- Subsurface relief (rock, sand, silt, probability of intermediate pinnacles or shoals requiring development etc.).
- Project economics (costs of surveys relative to engineering and design costs and estimated construction costs). ,
- Method of construction payment and/or computation thereof (in place, average end area, triangulated irregular network, etc.).
- Drawings plot scale (normally derived from above factors).

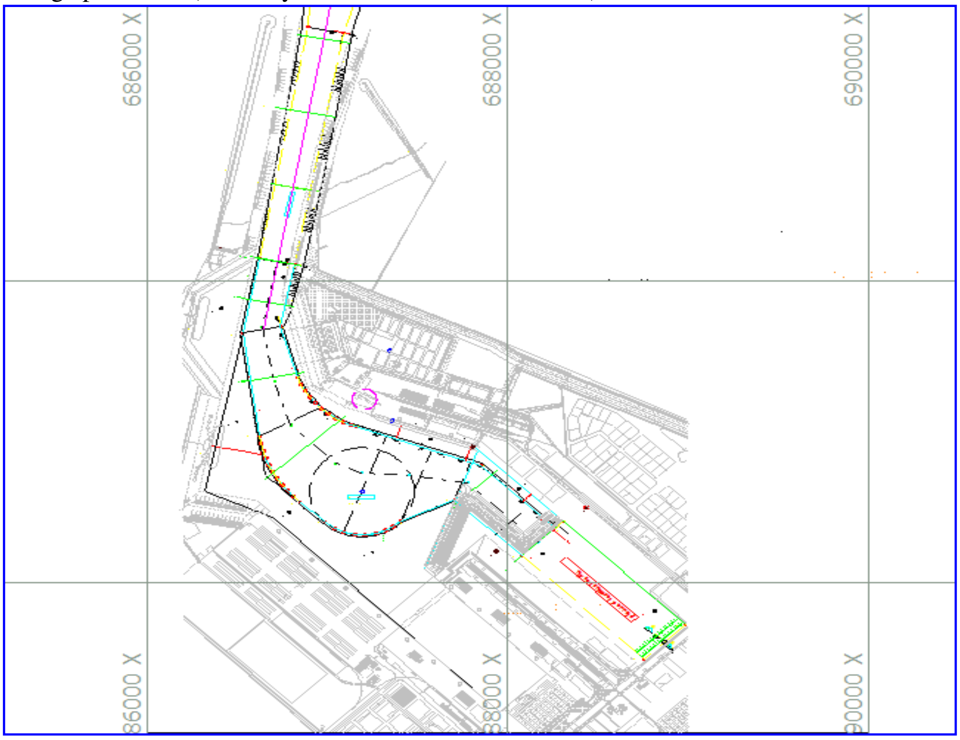

Figure (2): layout of Damietta port

5.1.2 The Used Equipments for Hydrographic Survey

The following survey equipments were used in the test:

<u>Shore Based Equipment:</u>

☒ LEICA 1230 GPS RTK Base Unit.
☒ Automatic Digital level Instrument LEICA DNA03
☒ Valeport740 Tide Gauge station

<u>Bathymetric System:</u>

☒ Dual frequency Echo sounder Knudsen 320M with the frequency 30KHZ Dual frequency Survey Transducer (210, 30 kHz).
☒ HAYPACK MAX Hydrographic survey software.
☒ Seatex MRU motion sensor;
☒ LEICA 1230 GPS RTK Rover Unit.
☒ Laptop with multi-serial cards.

<u>Office Based Equipments:</u>

☒ HAYPACK Hydrographic survey office software.

<u>Used Software:</u>

The hydrographic survey used specialized software "HYPACK MAX" (produced by coastal oceanographic Inc.). HYPACK® is one of the most widely used hydrographic surveying packages in the world, with over 10,000 users. It provides the surveyor with the tools needed to design their survey, collect data, process it, reduce it, and generate final products. Whether you are collecting hydrographic survey data or environmental data, or positioning your vessel in an engineering project, HYPACK® provides the tools needed to complete your job.

Motion Sensor:

Seatex MRU motion sensor was installed and used in the survey launch during all the time of survey. The unit incorporates 3-axis Micro-Electro-Mechanical-Structures (MEMS) sensors for both linear acceleration and angular rate. This unit achieves high reliability by using solid state sensors with no rotational or mechanical wear-out parts. It outputs data rate (100 Hz) with Dynamic accuracy (RMS): 5 cm or 5% whichever is highest.MRU outputs accurate heave measurements in the transducer head point instead of where the MRU is mounted.

5.1.3 System Installation

RTK Positioning System

We established and operate a short-range local reference RTK GPS positioning system, which consists of one RTK reference station and one or more RTK rover stations. This system was LEICA1230 RTK GPS.

I. RTK Reference Station:

A reference station was deployed at known, surveyed site, called base station. The receiver was augmented by a modem wireless that is capable of transmitting the base station data. The installation was done on the pre-defined control station. The base station was provided by Pacific Crest 35watt to cover the full area of the channel.

II. RTK Mobile Station

Mobile station was installed on board of the survey boat. The RTK raw data of the reference receiver via a radio link in order to solve the GPS phase observations ambiguity. The receiver was provided by the required Datum projection to output the results into the required grid.

Echo Sounder System:

The survey boat was equipped with over the side mounted dual frequency ODOM MKII transducer (30 & 210 KHz). This transducer was connected to Odom Echo sounder. The logged data shall consist of:

- Date and Time
- Fix particulars
- Raw depth.

Tide Measurements:

In order to maximize data return and to ensure confidence in the measured results, emphasis would be placed on:

- Quality control of data collected
- Thorough analysis of the resultant data sets
- Detailed recording of relevant instrument deployment details

A self contained VALEPORT740 tide-gauge is proposed, because it can be easily installed at a suitable jetty location and tied in to the Jetty (vertical) Datum (JD). The tide gauge was adjusted to record, at 5 minute intervals, relative water level. The tide gauge was installed in a safe location, in order that the data are not compromised by third party interference. The system comprises a logging and control housing connected via a power and data cable, to the pressure transducer. The transducer was fixed mounted on the jetty face and leveling surveyed to be connected with one of the control points by LEICA DNA03 level. The tide was recorded automatically and manually by the installed tide gauge and by manual observation on staff every 10 minutes.

5.1.4 Field Calibration

In this chapter, the calibration and check procedures are described which were performed to ensure that all surveys are executed in a proper and controlled manner.

RTK Calibration

To cover the highest accurate demands of DGPS, we took our DGPS to be based on Real Time or Post processing Kinematics of phase observations. This meant that we reached to the highest accuracy of GPS with fixing ambiguity On The Fly (OTF). To verify the quality control requirements, we used the following:

A calibration or site registration is needed in real-time surveying (RTS) in order to relate GPS positions that were measured in terms of the World Geodetic System 1984 (WGS-84) to local grid coordinate projections. A calibration was based on a set of points that have 3D coordinates in both WGS-84 and local grid coordinates projection system. The quality of the calibration was affected by the accuracy and consistency of the GPS coordinates of the points. The base Control points should be used as the basis of any calibration. At least four control points were used in a calibration process in the field such that Calibration points should be well distributed around the specified project area.

The Echo Sounder

The echo sounder was calibrated prior to and immediately after pre-interim-and final surveys by means of the bar check method. Most single beam, dual frequency and multiple transducer systems are calibrated by lowering a plate a fixed distance below the transducer then adjusting the "draft" and "sound velocity" settings on the echosounder. Checks and adjustments that were performed to determine the following variable parameters:

- Index error
- Scale error
- Squat factor

The index error is the depth of the transducer below the water level. Over a short time the Index error was considered constant during the survey process, but is must be recognized that the Index error will change as the draught of the boat varies over a long period (fuel and water consumption).

The scale error was influenced by the velocity of sound through water at the survey location. The velocity of sound through the water was the mean velocity obtained throughout the entire water column. The index and scale error was determined by use of the bar check method.

5.1.5 Survey Protocol

Prior to commencing the survey, the following items were checked:

- The Echo sounder was calibrated with a bar-check and sound velocity profile adjusted accordingly.
- The RTK rover unit was checked to an accuracy of a few centimeters accuracy.
- The appropriate alignment lines were surveyed as per the status of the survey and as per request of the survey specifications.

5.1.6 Planned Survey Lines

Planned survey lines as shown in figure (3) are used to define where the boat should go during the survey. Conventional sounding lines are run perpendicular, or as close as possible, to the general lines of contour Line space was 25 m. The lines cover both the bed width and slopes.

5.1.7 Starting the Field Measurements "The Survey Works"

After the completion of all preparations, such as setting up the positioning system, calibration of echo sounder and conducting a survey trial to add tide information to the software that receives the GPS information and depth data, the field survey started. The actual survey was done tracking the pre-planned survey lines, 25m apart, followed by reference line or check lines. The SURVEY Module program loads the information from the current project. It gets geodetic information and hardware information by reading the project's initialization files. It loads the most recently used planned survey line file from the current project, as well as any background files. The final data collection in the project was a final bathymetric map containing the depth data as shown in figure (4).

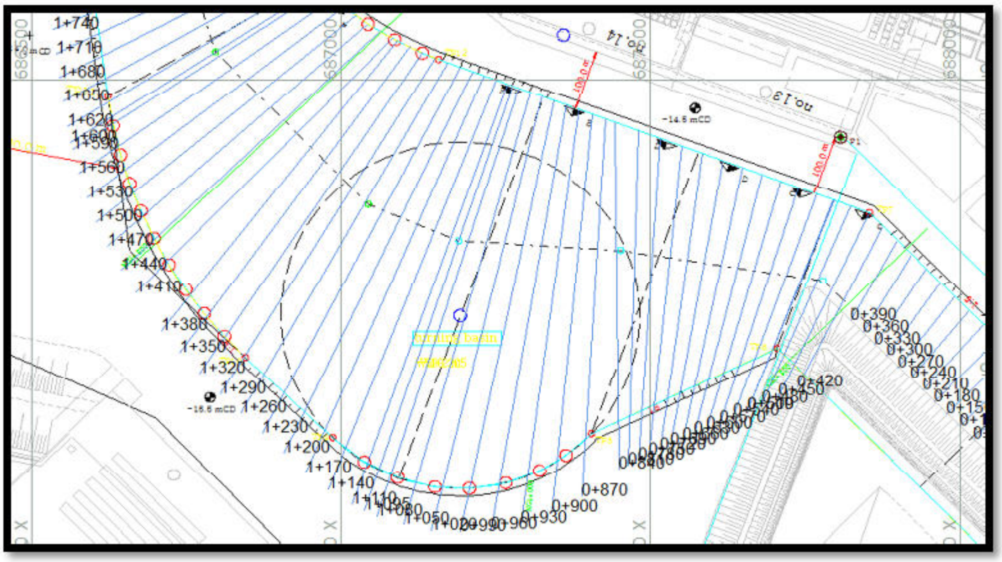

Figure (3): Planned Survey lines

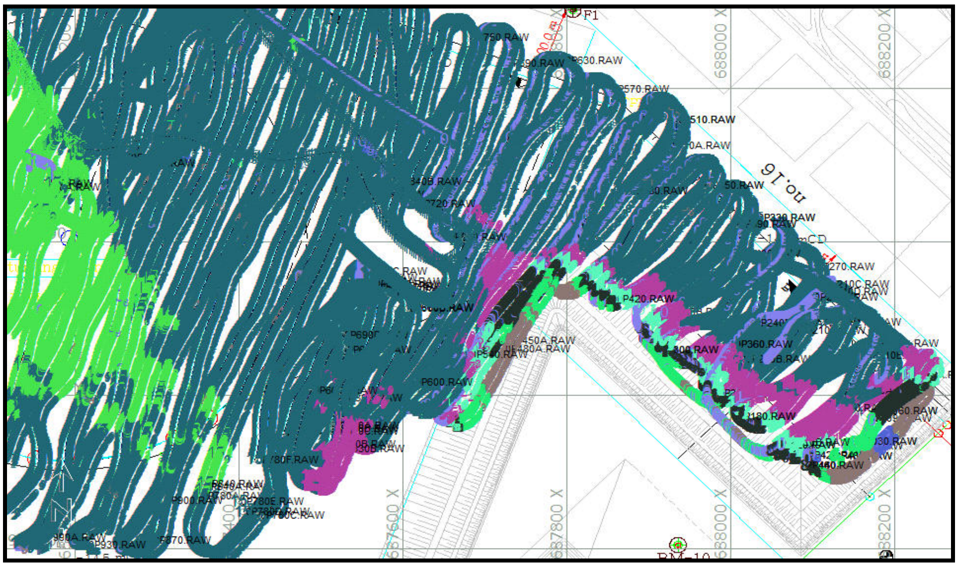

Figure (4): Collected Row Data

5.1.8 Raw Data Processing

The SINGLE BEAM EDITOR reads raw and edited sounding files containing single beam or dual frequency survey data. It applies tide and sound velocity corrections to the soundings to find corrected depth or elevation. Sound velocity corrections are applied in the editor programs during post-processing based on the data collected from a sound velocity probe. The sound velocity correction assigned to each sounding record is determined by the depth value, and the depth ranges and correction values specified in your Sound Velocity file. The editor calculates ray-bending corrections to sounding data as it is read into the program. When editing is complete, the program saves the corrected and cleaned data in xyz format for further TIN processing.

5.1.9 Dredged Quantity Computation at Damietta Port, Egypt

Channel Templates, also known as Cross Section Design Templates. Figure (5), is typically created in CHANNEL DESIGN based upon the geometry of the channel. The SURVEY program logs the template information directly to the header of the RAW data file. When editing the data file in the Editor program, the template information is displayed to the screen and is written to the header of the EDITED data file. The CROSS SECTIONS AND VOLUMES program use the channel template information found in the Base Survey data files, unless another template has been added in the Template column. The TIN (Triangulated Irregular Network) MODEL program creates surface models from XYZ. The TIN MODEL program creates a surface by connecting adjacent data points in optimized triangles, see figure (6). The volume computation was done, based on the created TIN model, by standard HYPACK methodology.

The following chapter deals with performing a heave study was done based on two assumptions:

The first assumption is done based o normal routine maintenance dredging works for Damietta Port where the dredged quantities are computed based on existing heave correction and non existing heave. The second assumption is done based on capital dredging works, i.e. increasing the chart depths of Damietta Port from 14.5m to 16.0m. The dredged quantities are computed based on the existing of heave correction and non existing heave.

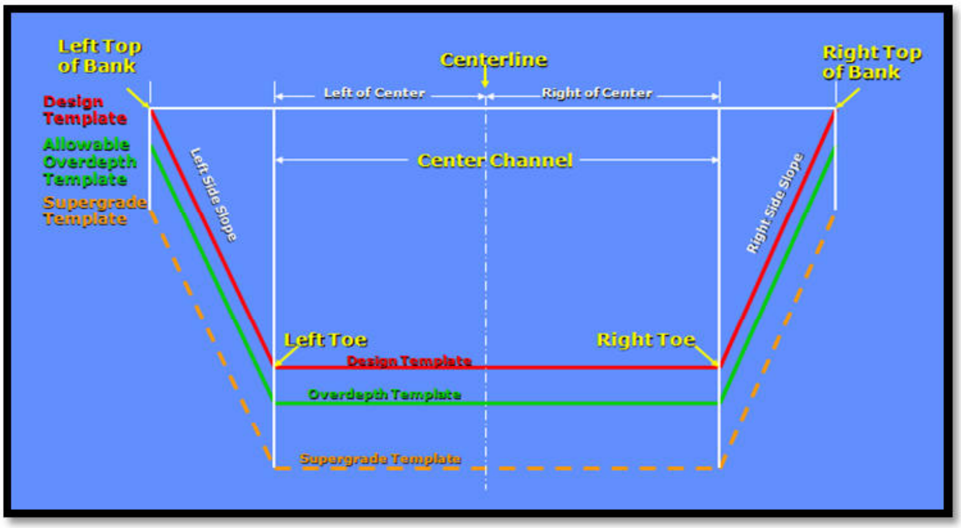

Figure (5): Cross Section Design Templates

Damietta Port Maintenance Dredging:

A siltation process occurs in Damietta Port within yearly average rates ranged between 900 to 1200 thousands m^3, the two thirds of sedimentation quantities are taken place between km2.5 to km5.5. The required Dredged Quantities for keeping the seabed of Damietta Port to a CD level of -14.5 m is performed along the different section of Damietta Port. Table (3) represents the computed quantities for DP different sections. The computed quantities were computed based on two assumptions: The first assumption was including the effect of Heave in the correction parameters of the sound depths, namely with heave,. The Second assumption was neglecting the heave effects in correcting the depths, namely without heave.

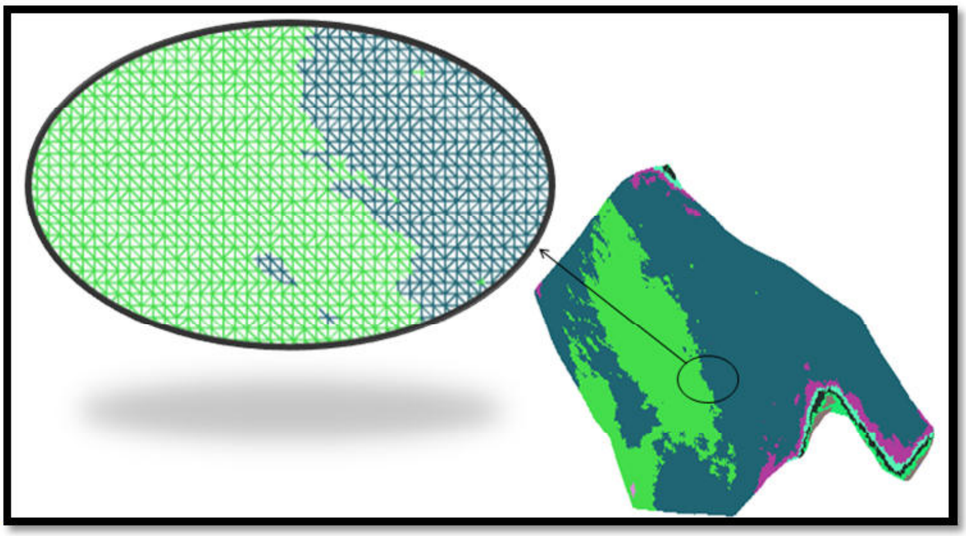

Figure (6): Triangulated Irregular Network

As it is demonstrated in table (2), the Volume of Dredged Quantity in Turning Basin is contradicting the normal heave effects in the rest of the DP's, mostly not to heave correction rather than errors in Sea bed digital model resulted from TIN. The maximum effect of both siltation and Heave is taken place in the sector from km 2.6 to km 3.6, where most of the disturbing currents occurred near the two ends of the breakwaters. A closing remark for this section, considering the heave effect along the full contaminated silty lengths of DP, with neglecting the turning basin quantities, one can see that the heave effect did not exceed %3 of the total dredged volumes.

Table (2): The computed quantities of dredged maintenance work at Damietta Port

Chainge Km	Without Heave	With Heave	Diff. m3	Rates
From 0.0 to 1.6	21902	21601	-301	-0.032
From 1.6 to 2.6	18840	19253	413	0.022
From 2.6 to 3.6	99915	104712	4797	0.048
From 3.6 to 4.7	142364	143258	894	0.006
From 4.7 to 5.7	48581	48869	288	0.006
From 5.7 to 6.7	31249	34032	2783	0.089
From 6.7 to 7.7	24149	24458	309	0.013
From 7.7 to 8.7	12787	14062	1275	0.100
From 8.7 to 9.4	5923	6172	249	0.042
Total (m^3)	383808	394816	11008	0.029

Damietta Port's Capital Dredging:

DPA is considered increasing the allowable navigation depth from 14.5 to 16.5 m as one of the inevitable important plans to increase the operation rate and income of the port. So, the current research work try to answer what is the effect of considering and not considering the heave correction on the measured quantities. So the previous computation process was repeated considering the design depth of the channel template to be set to 16.5m. Table (3) depicts the computed dredged quantities for the same sectors of DP with and without heave correction.

As it is shown in table (3), the maximum effect of both siltation and heave is taken place in the sector from km 2.6 to km 3.6, where most of the disturbing currents occurred in the areas adjacent to the ends of the two breakwaters. Generally the heave effects on the total dredged quantities along the full length of the DP channel does not exceed % 0.4 which is considered as allowable computing error.

Table (3): The computed quantities of capital dredged works at Damietta Port

Chainge Km	Without Heave	With Heave	Diff. m^3	Rates
From 0.0 to 1.6	704316	703969	-347	-0.0005
From 1.6 to 2.6	316557	317925	1368	0.004
From 2.6 to 3.6	488341	494287	5946	0.012
From 3.6 to 4.7	712958	714280	1322	0.002
From 4.7 to 5.7	486905	487814	909	0.002
From 5.7 to 6.7	520079	521377	1298	0.002
From 6.7 to 7.7	461012	461477	465	0.001
From 7.7 to 8.7	374189	376677	2488	0.007
From 8.7 to 9.4	221442	222707	1265	0.006
Total (m^3)	3581483	3596544	15061	0.004

5.2 The Second Test: Hydrographic Survey across the Virtual Navigational Channel of Boubyian Seaport

Boubyian Seaport is located in the Kuwaiti offshore in the Arabian Gulf adjacent to Iraq and Iran borders at Latitude 29^{o} 54' N and Longitude 48^{o} 18'E, as shown on figure (7).

5.2.1 The Used Equipments for Hydrographic Survey along Boubyian Port

The following survey equipments were used in the test:

Shore Based Equipment:

- LEICA 1230 GPS RTK System.
- Automatic Digital level Instrument LEICA DNA03
- Valeport740 Tide Gauge station

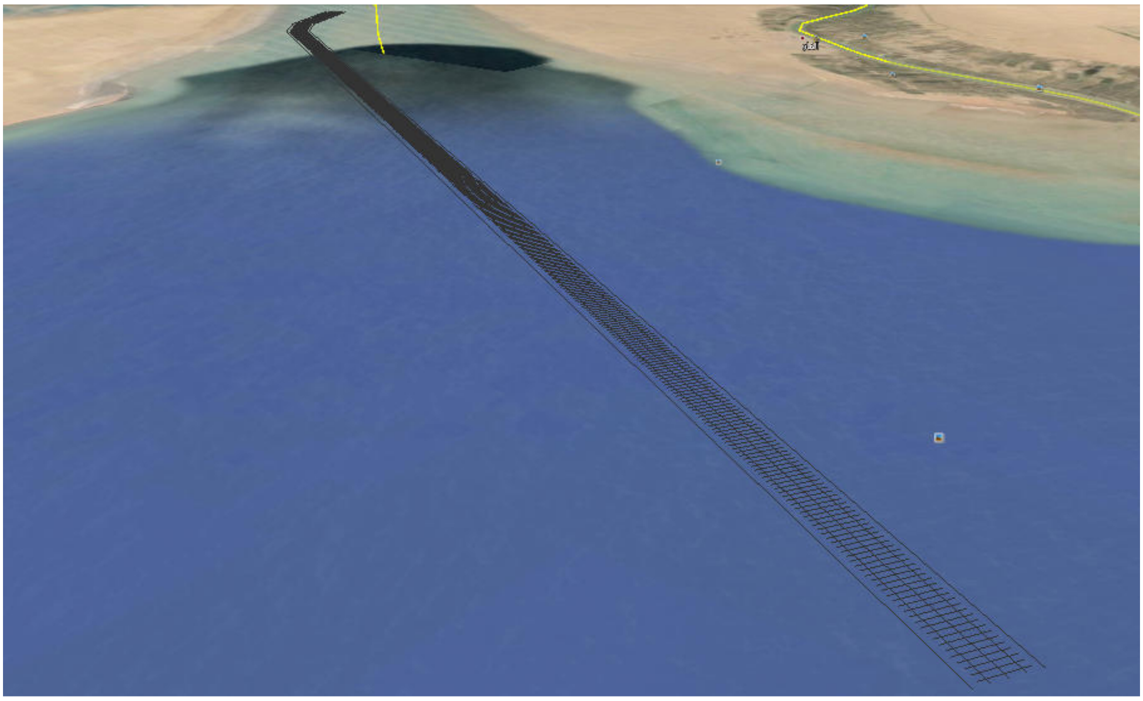

Figure (7) represents the layout of the proposed channel

Bathymetric System:

- ODOM Echotrack MKIII dual frequency Echo-Sounder
- Dual frequency Survey Transducer (210 , 30 kHz)
- HAYPACK MAX Hydrographic survey software.
- F185+ Positioning & motion sensor;
- As a backup positioning system we purpose R8 Geodetic RTK GPS mobile receiver or LEICA 1230 GPS RTK System.
- ODOM DigitalPro Sound Velocity Meter instead of Bar Check to measure the sound velocity
- Laptop with multi-serial cards.

Office Based Equipments:

- HAYPACK Hydrographic survey office software.

The Used Motion Sensor

The Octopus F185™ that was deployed in the survey of Boubyian Seaport is considered one of the best products in this matter (www.codaoctopus.com). It is an integration of GNSS with Inertial Navigation System. The Octopus F185™ with L1/L2 and 1cm RTK capability is a series of precision attitude and positioning systems has been expanded to include L1/L2 on the secondary antenna for rapid heading initialization and improved immunity to drop-out. For optimum performance in ports harbors and inland waterways, the F185 includes an integrated satellite-broadcast differential correction receiver, enabling it to receive corrections from subscription services and providing positional accuracy of up to 20cm without the need for any additional equipment.

5.2.2 Raw Data Processing

Sound velocity corrections are applied in the editor programs during post-processing based on the data collected from a sound velocity probe. The sound velocity correction assigned to each sounding record is determined by the depth value, and the depth ranges and correction values specified in your Sound Velocity file. The SINGLE BEAM EDITOR displays all measurements graphically as shown in figure (8). When editing is complete, the program saves the corrected and cleaned data in xyz format for further TIN processing.

5.2.3 The Proposed Boubyian Seaport Capital Dredging

As it is known, the port surveys are done to ensure that the waterways are free from obstructions and the depth is sufficient for safe shipping. Shipping safety depends not only on component navigation but adequate hydrography and up-to-date charts. The goal of the hydrographic survey of the proposed Navigational channel of Boubyian seaport is to assist the consultants to prepare the Bid documents with the bill quantities needed for construction companies to submit their prices to do the required dredging works.

The quantities of dredged works were computed based upon the Seabed design level is 16m below the Kuwaiti Chart Datum. The computed quantities were computed based on two assumptions: The first assumption was including the effect of Heave in the correction parameters of the sound depths, namely with heave. The Second assumption was neglecting the heave effects in correcting the depths, namely without heave. Table (4) displays the Volume of Dredged Quantity along the proposed channel from km0 to km46, considering sector every 5km.

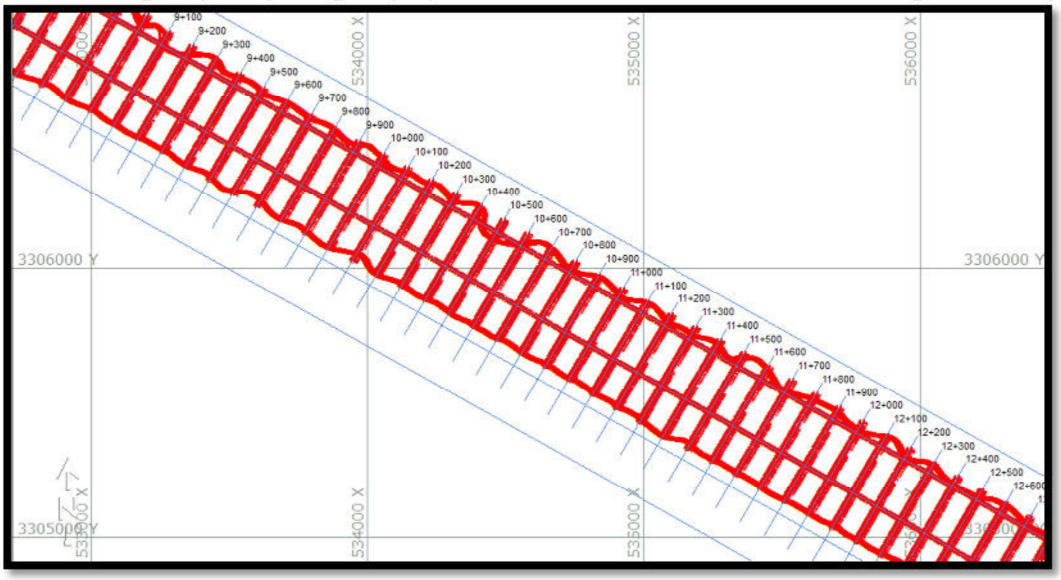

Figure (8): The Survey of the proposed Navigational Channel of Boubyian Seaport

As it is demonstrated in table (4), the Volume of Dredged Quantities is occurred in the sector of km5.0 to Km10, where the sea was slightly rough in this day of surveying. On the other hand, the heave effect on the dredged quantities is contradicting the normal heave effects in the rest of the channel in the two sectors Km35 to km40 and Km40 to km 46, mostly not to heave correction rather than errors in Sea bed digital model resulted from TIN. However, the heave effects on the total dredged quantities along the full length of the proposed navigational channel of Boubyian Seaport does not exceed % 0.3 which is considered as allowable computing error except in the sector from km5 to km10, which can be avoided by avoiding the hydrographic survey in rough sea condition..

Table (4): The computed quantities of capital dredging work at Boubyian Seaport

Chainge (Km)	Without heave	Heave	Differences m^3	Rate
From 0.0 to 5	**4568686**	**4574896**	**6210**	**0.001**
From 5.0 to10	**3743821**	**3824080**	**80259**	**0.021**
From 10 to 15	**3890892**	**3897378**	**6486**	**0.002**
From 15 to 20	**4142639**	**4158846**	**16207**	**0.003**
From 20 to 25	**3973830**	**3977106**	**3276**	**0.001**
From 25 to 30	**3269660**	**3274524**	**4864**	**0.002**
From 30 to 35	**1951876**	**1956160**	**4284**	**0.002**
From 35 to 40	**1591912**	**1588032**	**-3880**	**-0.002**
From 40 to 46	**824431**	**823224**	**-1207**	**-0.002**

6. Conclusions

To study the effect of heave on the computed dredging quantities, two single beam hydrographic survey tests were performed. The first test was done for routine maintenance and capital dredging works across a harbor, Damietta Port Egypt. The second test was executed along open sea, along a virtual channel, Boubyian Seaport in Arab Gulf. The heave effect study was done based on computing the dredged quantities computed by involving and non involving the heave correction in maintenance and capital dredging works for Damietta Port where the dredged quantities were computed based on increasing the chart depths of Damietta Port from 14.5m to 16.0m and also the capital dredging works for Boubyian Seaport.

The study shows that the heave effects on the total dredged quantities along the full length of Damiette Port does not exceed %3 & % 0.4 for both maintenance and capital dredging of the port. On the other hand, the total dredged quantities along the 46 km length of the proposed navigational channel of Boubyian Seaport does not exceed % 0.3, except in the sector from km5 to km10 that was surveyed in rough sea condition, which is considered as allowable computing error. Finally, one can say that the effect of heave on dredged quantities can be minimized, to be included in the allowable errors, by performing the survey in quite sea conditions.

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