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Recent Positioning Techniques for Efficient Port Operations and Development of Suez Canal Corridor

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Abstract - The majority of positioning systems for marine traffic are satellite based such as GPS. The developments of Real Time Kinematic Networks and their applications such as Virtual Reference Station are considered one of the recent high precision techniques for Global Navigation Satellite Systems (GNSS). These techniques will have great impacts on construction and operation of smart and efficient ports.

The advantages of using virtual reference station technique in different port operations and constructions have been discussed in this paper. To apply this technique in Suez Canal corridor zone, a design of GNSS Continuously Operating Reference Station network has been proposed. This network could be used during different construction and operations phases of Suez Canal Corridor project. The recommended system could reduce the time and cost of project constructions and improve navigation and safety through the Suez Canal.

Keywords - Suez Canal Corridor, RTK GPS, VRS, smart ports, vertical datum, dredging, under-keel clearance

I. INTRODUCTION

One of the main objectives of port authorities is maintaining safe movements of ships during entry, exit and inside the water area of the port. The efficient ports should perform continuous and economic services to ships without delay. The current development in satellite based positioning systems and their applications such as Virtual Reference Station (VRS) provide three-dimensional high precise positions which are critical for efficient ports.

The International Maritime Organization (IMO) issued minimum maritime user requirements for positioning for marine navigation as in Table (1). To meet these requirements, augmented GNSS is required in ports and port operations [1].

Table 1. Minimum Maritime User Requirements for Positioning.

	System level parameter			
	Absolute accuracy	Integrity		
	Horizontal/Vertical (Meters)	Alert limit (Meters)	Time to alarm (Seconds)	Integrity risk* (per 3 hours)
Ocean/ Costal/ Port approach / restricted waters	10 (H)	25	10	10^{-3}
Port	1 (H)	2.5	10	10^{-3}
Inland waterways	10 (H)	25	10	10^{-3}
Track control	10 (H)	25	10	10^{-3}
Automatic docking	0.1 (H)	0.25	10	10^{-3}
Ship-to-ship/-shore	10 (H)	25	10	10^{-3}
Search and rescue	10 (H)	25	10	10^{-3}
Hydrography	1-2 (H) 0.1(V)	2.5-5	10	10^{-3}
Oceanography	10	25	10	10^{-3}
Dredging	0.1 (H) 0.1(V)	0.25	10	10^{-3}
Construction works	0.1 (H) 0.1(V)	0.25	10	10^{-3}
Container/Cargo management	1 (H) 1(V)	2.5	10	10^{-3}
Cargo handling	0.1 (H) 0.1(V)	0.25	1	10^{-3}

*Integrity risk is the probability of providing a signal that is out of tolerance without warning the user in a given period of time.

The high accuracy GNSS techniques such as Real Time Kinematic (RTK) and network-based applications such as VRS are considered very efficient tools for precise port operations such as dredging, real-time under-keel clearance monitoring, hydrographic survey, terminal asset management, and other applications. With the draft of ships increasing mega ships capable of carrying more than 20000 TEU containers are now coming into service, it is now more crucial than ever that ports operate as efficiently as possible.

The network-based RTK positioning is very effective for port construction and developments such as Suez Canal corridor development project. This mega project in Egypt aims to increase the role of the Suez Canal region in international trading and to develop the three canal cities. In this paper a design of GNSS Continuously Operating Reference Station (CORS) network has been proposed. This network can be utilized during different construction and operations phases of the project. The efficient operations can be achieved in Suez Canal and all ports in the area by using the different applications of the proposed CORS network such as VRS.

II. POSITIONING SYSTEMS IN PORTS AND WATERWAYS

Presently, the use of land based positioning systems for waterways such as Loran-c is becoming uncommon due to its cost and low accuracy. The accuracy specification for Loran-C is a 95 percent probability of a radial error within 400m over water. However, differential Loran can achieve accuracies of order 10m at selected locations, such as airports and harbors [2]. The majority today use satellite based systems such as GPS. The IMO has recognized that Global Navigation Satellite System (GNSS) will improve, replace or supplement existing position fixing systems since some of which have shortcomings with regard to integrity, availability, control, and system life expectancy.

A. Differential GPS Positioning

Differential Global Positioning System (DGPS) is an improvement to navigation solution of a standalone GPS receiver. The position accuracy might improve from the 15-meter nominal GPS accuracy to reach decimeter level in case of the best implementations [2].

DGPS uses a network of fixed, ground-based reference stations to broadcast the difference between the positions determined by the GPS and the known fixed positions of the stations. These differences are received by the users as corrections which can be applied to improve the accuracy of their GPS positions as in Figure 1.

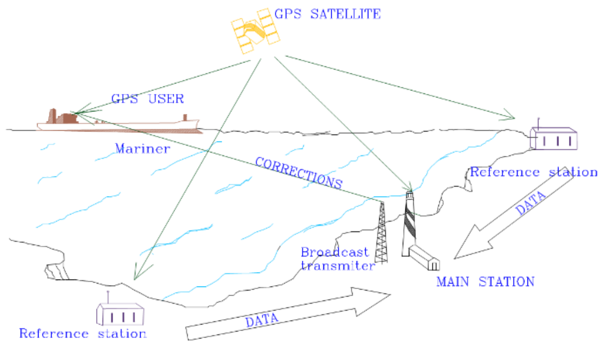

Fig .1 Concept of DGPS

The DGPS network in Egypt consists of six control stations, each has one reference station and radio beacon broadcast site with integrity monitoring and communications links. Along the Mediterranean, three sites (Mersa Matruh, Alexandria, and Port Said) provide coverage for Egypt's north coast. The three southern sites (Ras Umm Sid, Ras Gharib, and Quseir) provide coverage from the northern end of the Gulf of Suez south to Egypt's border with Sudan as shown in Figure 2. Port Said and Ras Gharib together also provide full and overlapping coverage of the Suez Canal and the oil fields in the Gulf of Suez.

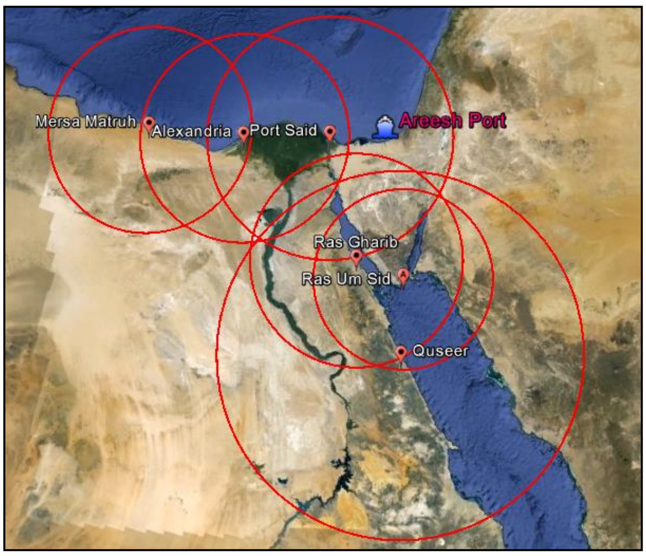

Fig .2. Coverage of DGPS service in Egypt [3]

B. *Real Time Kinematic GPS Positioning*

Real Time Kinematic GPS allows the user to obtain centimeter-level positioning accuracy in real-time. The basic concept behind RTK is that a base station receiver is set over a known point and sends the observed GPS data to other rover receiver [4]. The rover receiver is equipped by a controller which has software capable to process the double difference GPS data of both receivers and resolve the integer phase ambiguities. Once the integer ambiguities are correctly resolved, the position of the rover station can be determined with accuracy reach centimeter level in real time while the station is in motion [5]. The base station data is normally sent via UHF or spread spectrum radios that are built specifically for wireless data transfer as in Figure 3.

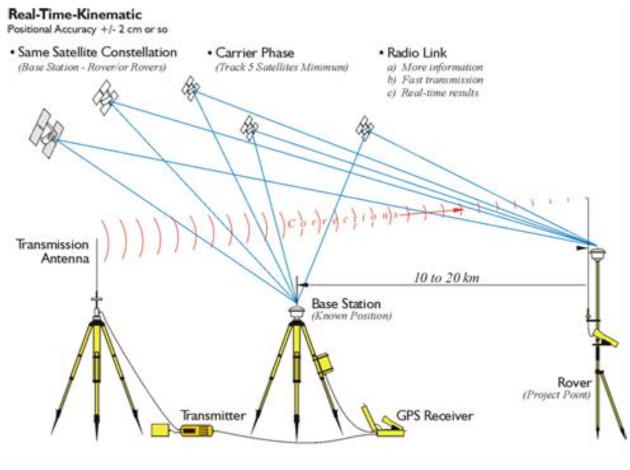

Fig .3. Real Time Kinematic GPS technique

C. *Network RTK and Virtual Reference Stations*

The Virtual Reference Station is a concept which helps to reach centimeter-level, or even better accuracy of positioning by using single receiver. It requires the use of dual-frequency carrier phase observations using a network of reference stations. These observations are usually processed using a differential GPS algorithm, such as RTK.

GPS network configuration such as CORS networks often makes use of multiple reference stations. This approach allows a more precise modeling of distance-dependent systematic such as ionospheric and tropospheric refractions, and satellite orbit errors [5]. The network of receivers is linked to a main control center, and each station contributes its raw data to create network-wide models of the distance-dependent errors. The computation of errors based on the full network's carrier phase measurements involves the resolution of carrier phase ambiguities and requires knowledge of the reference station positions. At the same time, the rover calculates its approximate position and transmits this information to the computation server, via Internet Protocol. The computation center generates in real time a virtual reference station at or near the rover position as shown Figure 4. This is done by geometrically translating the pseudorange and carrier phase data from the closest reference station to the virtual location and then adding the interpolated errors from the network error models. When VRS data received, the rover receiver uses standard single-baseline algorithms to determine the coordinates of the user's receiver, in RTK or post-processed modes [6].

In the VRS positioning, many techniques can be employed such as the virtual reference station method (VRS) and the area correction parameter technique. These methods have differences in the amount of data to be sent to the user, the processing strategy, amount of computations at the station, and the type of communications between the network and the rover receiver. The objective is to avoid the distance dependent decrease of accuracy and the equivalent increase of the required time to fix ambiguities.

In order to dominate the distance dependent errors in real-time applications, it is necessary to perform a real-time data analysis using all data from the participating reference stations. In practice, this means that all reference stations need a data link to a computing server where the analysis is executed in quasi real-time, and the distance dependent errors coming from the orbit, the ionosphere, and the troposphere are estimated. This information is then used to correct the results at any given station within the working area. The technique could be named "interconnected reference network", "linked network", or "coupled network". The main advantages of the Network RTK can be summarized as follows [7]:

- Cost and labor reduction, as there is no need to set up a base reference station for each user.

- Accuracy of the computed rover positions is more homogeneous and consistent as error mitigation refers to one processing system.

- Accuracy is maintained over larger distances between the reference stations and the rover.

- The same area can be covered with fewer reference stations compared to the number of permanent reference stations required using single reference RTK. The separation distances between networks stations are tens of kilometers, usually kept less than 100 km.

- Network RTK provides higher reliability and availability of RTK corrections with improved redundancy, such that if one station suffers from malfunctioning, a solution can still be obtained from the rest of the reference stations.

- Network RTK is capable of supporting multiple users and applications.

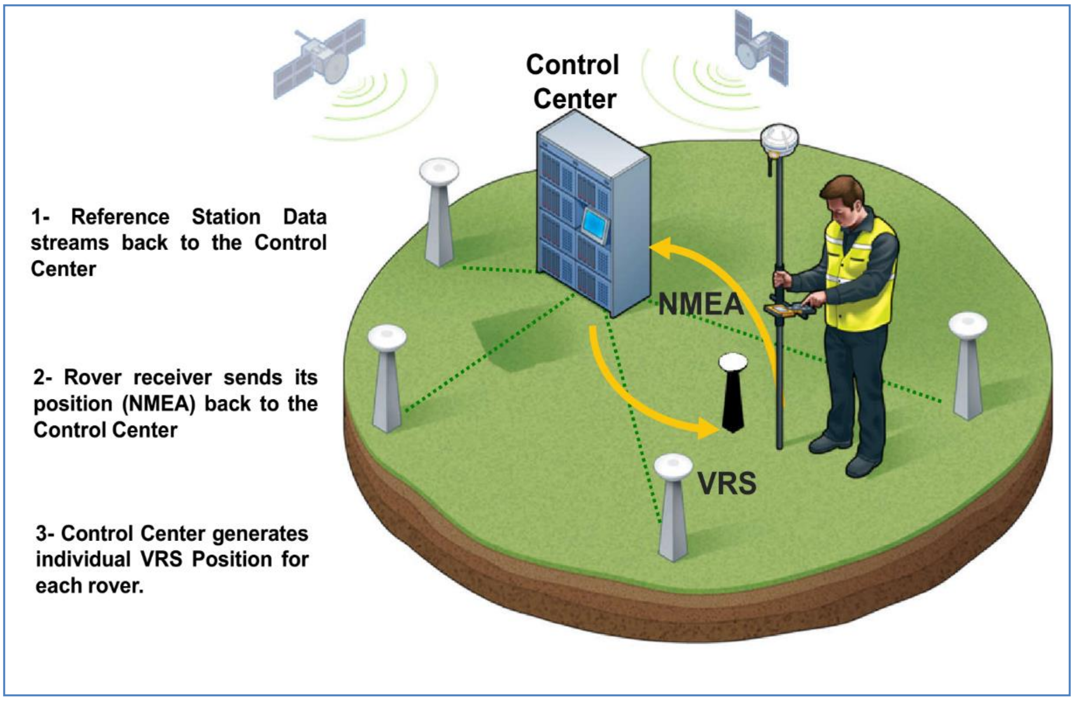

Fig .4. Virtual Reference Station concept

III. RTK APPLICATIONS IN PORT OPERATIONS

A RTK system is a precise and accurate system for both horizontal and vertical measurements and centimeter-level accuracy could be obtained over a large site. The RTK systems have many benefits and applications which can be used in numerous activities at ports such as:

- Hydrographic surveying of the ports water area and navigation channels.

- Precise and economic dredging and construction of quay walls and coastal protection.

- Ship under-keel clearance monitoring, berth docking and piloting systems.
- Precise tracking for position and speed to feed into the vessel tracking systems.

- A positioning system infrastructure for terminal asset management.

This paper focuses on the advantages of using RTK network and its application VRS in hydrographic surveying, dredging, and real time under-keel clearance monitoring.

A. Advantages of Using RTK in Hydrographic Surveying

The hydrographic survey mainly depends on measuring the horizontal and vertical position of the survey vessel. The accuracy of the vessel positioning

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directly affects the accuracy of the seabed survey.

Conventional hydrography determines a chart depth by measuring the distance from the sounding transducer to the bottom and then applying corrections for draft and tide. RTK GPS receivers can measure the latitude, longitude and height above the WGS-84 reference ellipsoid to within a few centimeters. Using this vertical accuracy, water level corrections (tide corrections) can be determined. This eliminates the need to use conventional tide gauges or to assign personnel to monitor tide staffs. The separation between the WGS-84 reference ellipsoid and the appropriate chart datum of the survey as it has to be pre-determined area. Figure 5 illustrates the relationship between different vertical datums in hydrography.

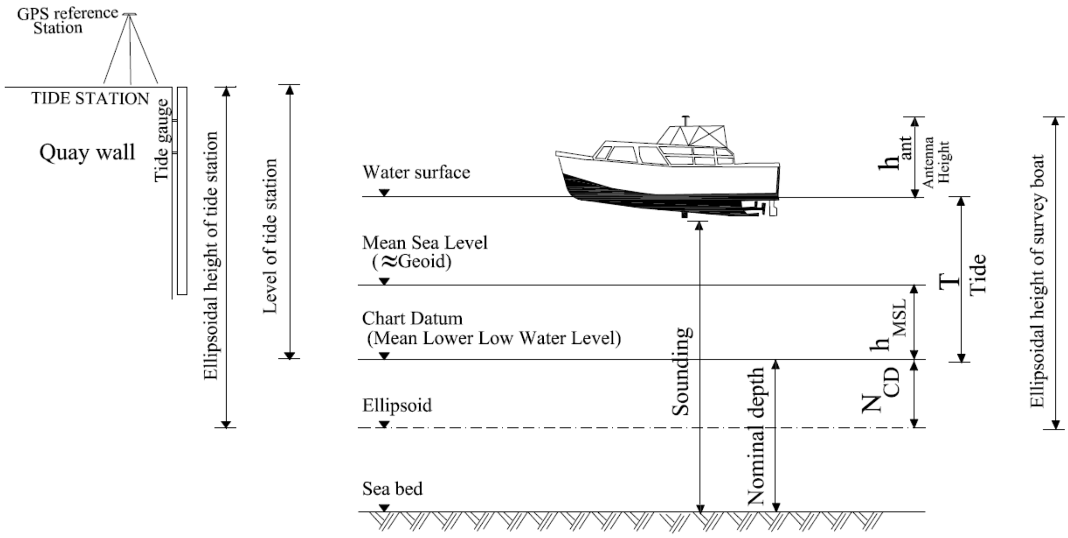

Fig .5 Relationship between different vertical datums in hydrography.

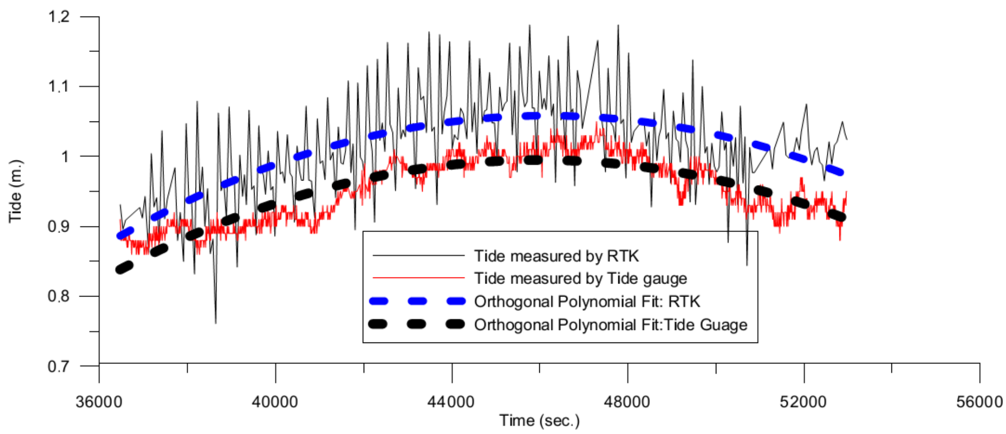

Fig .6 Tide values measure by the tide gauge and by RTK GPS [3].

Tide gauges can only report the tidal condition at the place where they are installed and they cannot measure other long waves at the vessel position. In case of projects located far from the tide gauge, significant differences may occur. To investigate these differences data obtained during a maintenance dredging project in Port Said East Port were utilized [3]. Figure 6 depicts the tide values measured by both the tide gauge and RTK GPS for an area about 10 km away from the tide gauge. Data obtained during a maintenance dredging project in Port Said East Port were utilized. It becomes clear that there is nearly a 10 cm gap between the measured values in each case. Tide measurements at the location of tide gauge diverge from the tide values at the project site due to the change in the sea state conditions and other factors. The limitation of using RTK GPS for measuring tide is the assumption that the separation between ellipsoid and CD for the project area is constant where the gradient of chart datum is considered zero.

Many errors associated with GNSS positioning can be eliminated through careful calibration procedures prior to each survey. The remaining errors affect the measured coordinates depending on the type of equipment and measurements technique. Figure 7 illustrates an example of effect of error in horizontal position of survey vessel on the measured depth and consequently on the calculated dredged volume. In areas with flat bottom, this effect may not be significant.

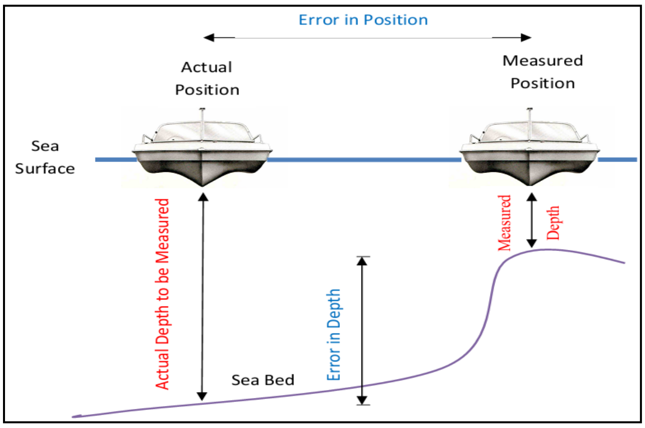

Fig .7 Example of effect of errors in position on the measured depths

B. *Precise and Economic Dredging and Construction*

Using the RTK network provides centimeter-level accuracy for both horizontal positioning and depth. Therefore, possibilities of missing spot shoals are decreased. Also, knowing accurate draft of the vessel enables increased accuracy for dredge cuts. In addition, the improved accuracy makes dredging around piers and pilings easier [8].

To inspect the effect of the used positioning equipment on the estimated dredged volume, an experiment has been carried out in Arish Port. Hydrographic survey has been performed using two different positioning equipment RTK GPS model Leica 1230 and DGPS model Trimble DSM132. ODOM ECHOTRACK single frequency Echo-Sounder is used for depth measurements and HAYPACK MAX Hydrographic survey software V.6.2b is used for data collections and processing [3].

Figure (8) shows spot height differences of Areesh Port obtained using RTK GPS and DGPS positioning systems. The spot height differences range from -2.56 m to 1.48m with -0.03 m mean and 0.32 m standard deviation. The estimated dredging volume to level (-13 m) is 977603 and 974474 cubic meters in case of using DGPS and RTK GPS, respectively. Considering the average cost of dredging is 7$ per cubic meter, the direct difference in cost is 21903 $, which is nearly the difference between the purchasing cost of RTK GPS and DGPS.

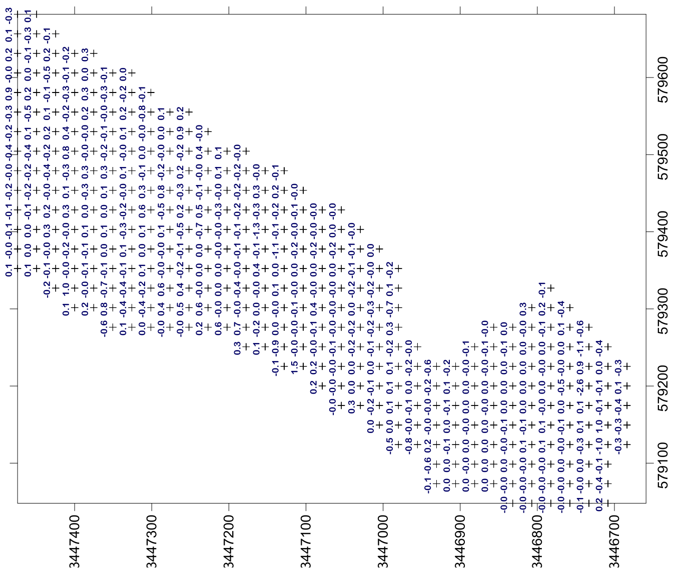

Fig .8 Differences in hydrographic survey results using DGPS and RTK (all dimensions are in meters)

To investigate the effect of using RTK GPS in tide measurements, the volume of the dredged materials of Port Said East Port maintenance dredging project has been calculated. The volumes of the dredged materials were 1,874,363 and 1,610,095 cubic meters estimated by using RTK GPS and tide gauge, respectively. The difference in volumes is a considerable amount and has a significant impact on the project cost.

C. Real-time Ship Under-keel Clearance Monitoring

Under-keel Clearance (UKC) is the most important factor which determines the possibility of ship hull touching the bottom; therefore it is one of the basic elements which decide navigation safety in restricted waters. The basic navigator's responsibility is to keep under-keel clearance safe in any conditions. Typically, a channel is dredged to a defined depth and any deep draft vessel exercises a margin of safety such as entering port in high tide, or exiting with a lighter load. It is recommended to reduce UKC without compromising safety for less cost and reduce possible environmental impact of dredging [9]. The total allowance or Gross UKC can be diagrammatically represented in Figure (9).

In addition to the conditional factor allowances identified in Figure (9), most real-time UKC calculations include a "Bottom Clearance", which refers to the remaining clearance allowance required after all other conditional factor allowances are removed. The Bottom Clearance allowance is based on internationally accepted guidelines, and is intended to be a representation of the Gross UKC value.

There are a few technologies available for UKC measurement using GPS. Dynamic UKC technique characterizes the performance of each class of ship in the port area. This is carried out by using precise GPS while sailing in and out. For following up port entries, that data are used plus wave buoy information, nominal draft, vessel speed and wind data and report in real-time on the actual draft. Another technique is to install RTK GPS receivers on deep draft vessels so that the precise absolute depth of the keel is known independent of tide gauges and changing vessel draft. When combined with an accurate digital terrain model of the navigable depth of the port , the UKC can be determined.

The ability of RTK GPS receivers to determine the altitude of fixed points on the vessel relative to a known vertical datum means that the potential exists to bypass the measurement of tide heights, ship drafts and local sinkage in determining the elevation of a ship's keel relative to chart datum. When combined with charted bathymetry, the under-keel clearance can then be obtained. The RTK GPS concept for monitoring real-time ship under-keel clearance is shown in Figure 10 and Equation 1&2 [11].

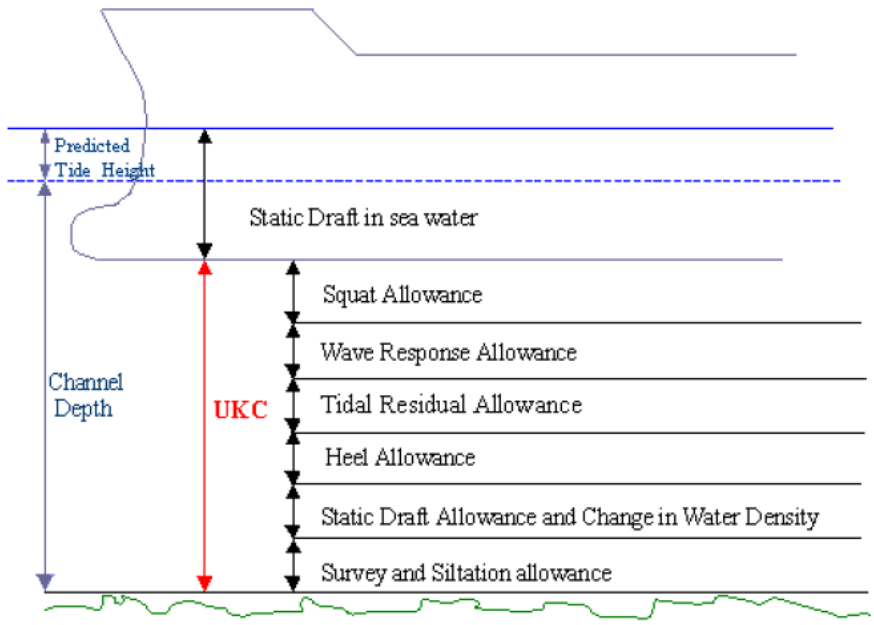

Fig .9 Factor allowances associated with a Gross UKC Calculation [10]

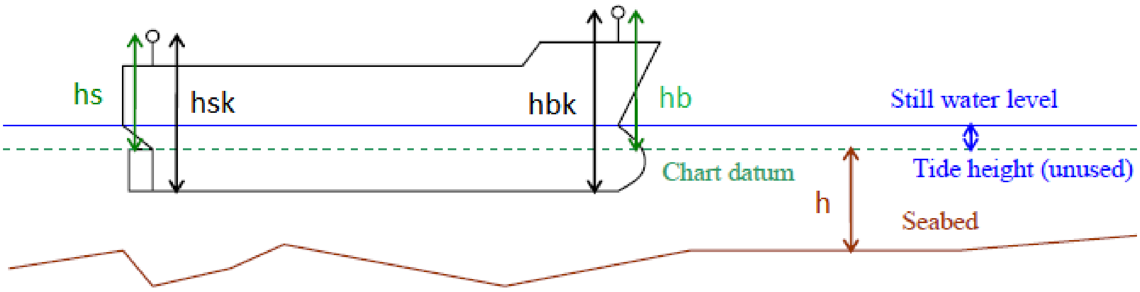

Fig .10 GPS concept for monitoring ship UKC [7]

Real-time UKC at bow = h+hb-hbk (1)

Real-time UKC at stern = h+hs-hsk (2)

Where hs is stern GPS altitude, hsk is stern GPS altitude above keel, hb is bow GPS altitude, hbk is bow GPS altitude above keel, and h is water depth. Similar relations are used at other points on the ship.

Overseas operational experience confirmed that applying a real-time UKC monitoring systems give greater understanding of the margin of navigational safety and increase the potential for economic benefit to the users by permitting increased cargo uplift [10].

IV. APPLICATIONS OF CORS NETWORKS IN DEVELOPMENT OF SUEZ CANAL CORRIDOR

The Suez Canal Corridor Area SCCA Project is a mega project in Egypt. The project's aim is to increase the role of the Suez Canal region in international trading and to develop the three canal cities: Suez, Ismailia, and Port Said. The project involves building new Ismailia city, an industrial zone, fish farms, completing the technology valley, seven new tunnels between Sinai and Ismailia and Port Said, and improving five existing ports.

Such a mega and promising project could benefit from the advantages of GNSS networks during the construction and operation phases. There is an endless number of potential applications that might benefit by VRS and GNSS networks. Figure (11) shows the proposed CORS network for SCCA.

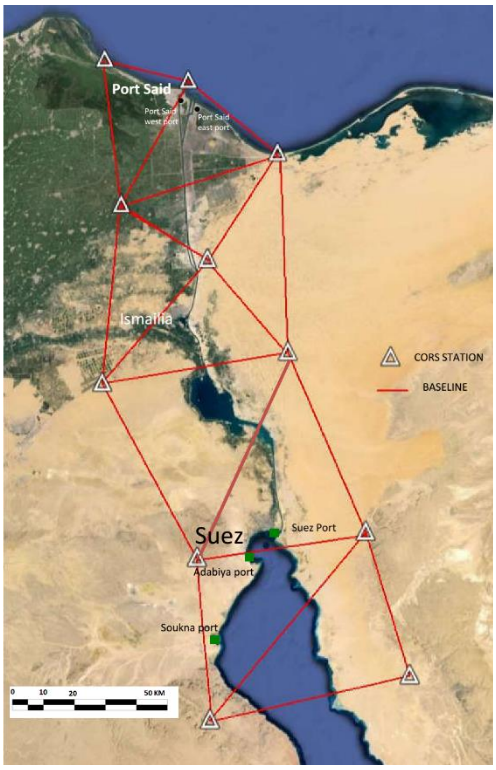

Fig .11 The proposed GNSS network in Suez Canal Corridor Area

CORS Station location follows some requirements needed to provide a good network in terms of geometrical arrangement around the area of interest. This was done by carefully selecting locations which were strategically viable for installing this kind of technology. The proposed baseline lengths for the network range from 30 km to 70 km. Some factors need to be considered before a Base Station can be installed in a particular location and these are following:

- Location where the instruments receiving antenna can clearly view the sky above and no obstruction hindering them from gathering satellite data. 360o view of the horizon and 5o elevation mask is recommended.
- Locations where one can get good geometrical network by positioning it to an evenly spaced network forming an interconnected triangular polygon in each and every location.
- Locations far away from the nearby transmitters, it is recommended to position it 300 meters or more away from these structures.
- Avoid locations where there are unstable environmental conditions such as: thermal expansion that can cause shifting of position, excessive wind forces that can bend materials that are supporting the receiving antenna and condition where there is an unstable ground that can generate structure settlement and shift the original position because of excessive tilt.
- Locations where security procedure is tight enough to guard this kind of installation.
- Accessibility of the installation must be in good condition as much as possible in order to get into this installation directly whenever there are troubleshooting issues that needs to be addressed immediately.

A. Benefits of CORS in SCCA during Construction Stage

The construction stage of SCCA project includes the building of roads, highways, tunnels, quay walls, terminals, factories and water and electricity infrastructure and many other constructions. There are numerous existing and potential applications of GNSS technology in this area. The majority of major construction projects now utilize precision guidance in site surveying and earthmoving. With regard to earthmoving, adoption rates of machine control systems are steadily increasing and information obtained from suppliers of precision GNSS equipment indicates very high degree of accuracy at the growth in sales of machine control systems in construction that are among the highest of any precision product line.

VRS technology allows surveyors to determine critical coordinates instantly without the need for calculations with centimeter-level of accuracy. The high accuracy obtained from the use of VRS means fewer mistakes are made and checking processes can be performed quickly and easily. Importantly, the accuracy and reliability obtained by GNSS means that less site rework is required thus benefiting both surveyors and construction parties relying on the survey information.

The application of machine guidance technology to earthmoving machinery has been one of the biggest growth areas for precision GNSS equipment. Precision GNSS technology allows for site plans to be programmed into earthmoving equipment, such as bulldozers, excavators and graders. The earthmoving equipment can then be controlled to conform to the site plan via the use of continuously
updated GNSS positioning information. Conventional earthmoving involves a significant amount of rework, or machine passes, to provide an accurate finish. In addition, conventional methods require surveyors to be continually on site to stake out routes. Precision GNSS technology, however, significantly reduces the amount of rework and in some cases completely negates the need for surveyors to stake out routes.

CORS network and its application VRS, as applied to construction earthmoving, results in significant benefits. These benefits are outlined in Table 2 and Table 3 [12].

Table 2. Benefits of CORS/VRS in Land Surveying [12].

Time savings	• Negates the need to set up control points when starting a new project – 0.5-1 day saved per project • Reduces time spent doing manual calculations • Reduces time spent in the office – from 40% to around 10% per project • Time savings of up to 75% for large projects and 60% for small projects are possible
Labour savings	• Reduces the number of surveyors required for a project from 50 to about 10 for large projects • Allows for the use of non-survey staff to do simple mapping tasks that would otherwise require a qualified surveyor
Infrastructure savings	• Reduces the need for traffic disruptions, such as lane closures, and associated risk to survey and road workers
Safety improvements	Reduces the need for maintenance of ground marks

Table 3. Benefits of CORS/VRS in earthmoving in construction [12]

EARTHMOVING IN CONSTRUCTION	
Time savings	• Reduces project time significantly – savings of between 30% and 80% are possible • Negates the need for surveyors to physically stake out routes • Negates the need to navigate machines around stakes and pegs • Reduces the frequency with which dirt is moved around a site by up to 60% • Reduces the time spent conducting as-built surveys
Capital savings	• Productivity of bulldozers, excavators and graders is significantly increased • Reduces the amount of re-work up to 70% • Reduced need for support machines • Reduced downtime
Labour savings	Fewer workers are required for a project
Safety improvements	• Reduces the number of workers on a site and in close proximity to machines, particularly workers with grade stakes and string lines
Quality improvements	• Work is generally more accurate – e.g. grader trimming

B. 2 Benefits of CORS in SCCA during Operation Stage

CORS applications and benefits during operation of SCCA projects are varied. There are many applications in ports operations as mentioned before. The proposed CORS network could improve navigation through the Suez Canal and permit vessels to transit in all weather condition, which keeps the Canal open all times for ship transits. Using VRS technique through Suez Canal will provide real-time 3D monitoring of the vessel position and UKC improving navigational safety. The proposed network will keep controlled piloting and berthing, so minimal damage to infrastructure and ships occurs.

CORS may have relevant benefits and applications in operation of SCCA projects such as container terminals management, intelligent transport systems, assets management,etc. [13].

V. CONCLUSION

This paper shows the current development in GNSS positioning techniques and its impact on both construction and operations of ports. The benefits of

RTK GPS in hydrographic surveying, dredging and UKC monitoring are discussed and examined. The results agree with the previous studies and showed that using RTK GPS networks and its application VRS could be more economic and accurate than other positioning system such as DGPS.

In this paper a design of GPS Continuously Operating Reference Station network has been proposed. The benefits for this network have been discussed for different construction and operations phases of the project. The efficient operations could be achieved in Suez Canal and all ports in the area by using the different applications of the proposed CORS network such as VRS.

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