MINISTRY OF EDUCATION AND TRAINING
HANOI UNIVERSITY OF MINING AND GEOLOGY

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RESEARCH ON APPLICATION OF REAL TIME KINEMATIC GPS IN HYDROGRAPHIC SURVEYING FOR MARITIME SAFETY IN VIETNAMESE CONDITIONS

MAJOR: SURVEYING AND MAPPING ENGINEERING

CODE: 9.52.05.03

SUMMARY OF THE DOCTORAL THESIS

HANOI - 2021

The thesis has been completed at the **Department of Advanced Geodesy, Faculty of Geomatics and Land Administration**
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The thesis will be defended before the Examination Board
at Hanoi University of Mining and Geology,
at …… o'clock dated ……..

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INTRODUCTION

1. The necessity of the thesis

Vietnam has a coastline of more than 3260km and next to international sea routes. Vietnam's sea has an important strategic position in the cause of national economic development, national defense and security, national sovereignty and territorial integrity. In recent years, watercraft operating in the sea area, navigational channels, Vietnam's ports have increased in both quantity and tonnage. The fact shows that the role of ensuring safety for maritime traffic activities is very important. In order to perform this role well, surveying and providing timely and accurate hydrographic data on horizontal positioning, depth of topography, terrain, dangerous maritime obstacles, etc. on shipping channels and water areas in the coastal waters of Vietnam are extremely important.

In the echosounding technology integrated with GNSS, the determination of coordinates usually uses the DGNSS or GNSS Base methods depending on the accuracy requirements and the measuring area. Currently, the Vietnam Department of Surveying, Mapping and Geographic Information and some specialized agencies have built a lot of GNSS CORS stations supporting of a wide variety of applications but GNSS CORS stations have not been studied and applied for hydrographic survey to maritime safety. If taking advantages of the GNSS CORS stations that have been built in the coastal areas for hydrographic survey to maritime safety, it will save lots of time and money for the establishment of GNSS Base stations.

Depth of seabed is measured by using echo sounder with add up tidal value is obtained at the tide station established near main land to survey area. The chart depth is referenced based on the lowest astronomical tide level at the coastal tidal station. However, the lowest sea surface (LSS) in different sea areas will not be the same, so when referring to the results of depth measurement of the seabed topography to the LSS at the coastal tide station, there is no scientific basis. Nowadays, there are a lot of jobs using GNSS RTK to determine the height of the water level at the position of the depth measurement point in the sea. However, Vietnam has not published the national quasigeoid model, it is not appropriate to use the height anomaly from the global quasigeoid model to correct the measured depth.

The most important task of the thesis is researching and applying GNSS CORS RTK technology in hydrographic surveying for maritime safety; study

the method of correcting the influence of tides in the depth of the seabed topography based on the MIKE 21 FM model and studying the scientific basis for the processing of seabed topographic depth data based on the lowest sea surface model to ensure uniform accuracy and consistency of data on the coastal waters of Vietnam.

Because of the above reasons, the thesis "Research on Application of real time kinematic GPS in hydrographic surveying for maritime safety in Vietnamese conditions" shows the necessity, current affairs, have scientific and practical value, to contribute to the improvement of the efficiency of the field measurement; serve as a basis for supplementing and perfecting bathymetry standards for safety of navigation hydrographic surveys and creating a scientific basis for establishing a unified chart database on Vietnam's coastal.

2. Research purpose, object, and scope

- ***Overall Purpose:*** Establishing the scientific basis and method of integrating real-time dynamic GNSS technology (using CORS GNSS station system) with echo sounder and referencing depth measurement technology in coastal sea areas based on Sea surface models in hydrographic surveying for maritime safety in Vietnam's conditions.

- ***Detail Purpose:*** Establishing a scientific basis for integrating GNSS CORS RTK technology and echo sounding technology in hydrographic surveying for maritime safety; Proposing a method of referencing the water level elevation is determined from the MIKE21 FM model to correct the depth's seabed topographic measurements in the coastal area in Vietnam; Proposing a reference method for the depth's seabed topographic measurements data based on the lowest sea surface model in the coastal area of Vietnam.

- ***Research object:*** Scientific issues related to the integration of GNSS CORS RTK technology with echo sounding technology to determine coordinates and depth’s seabed topography; processing depth measurement data and referencing seabed topographic depth measurements based on the lowest sea surface models to maritime safety in Vietnam's coastal areas.

- ***Research scope:*** The scope of the study is limited to the application of GNSS CORS RTK technology integrated with echo sounder technology and processing of seabed topographic data based on the MIKE 21 FM model and the lowest sea level model in seabed topographic depth measurement to establish nautical charts and shipping channel topographic plan for maritime safety in Vietnam's coastal areas (range from buoy number "0" of channel to land).

3. Research contents

(1) Collecting and analyzing domestic and international scientific documents related to the application GNSS RTK technology in hydrographic surveying for maritime safety in Vietnamese conditions; (2) Research and application of GNSS CORS RTK technology in hydrographic surveying for maritime safety; (3) Research and integrate GNSS CORS RTK technology with echo sounder technology in hydrographic surveying for maritime safety; (4) Studying the method of determining the water level based on the MIKE 21 FM model and referencing the observed water level based on the lowest sea level model model; (5) Research and development of a reference method for seabed topographic depth measurement based on lowest sea level model model; (6) Experimental integration of GNSS CORS RTK technology, referencing water level measurements from MIKE 21 FM model and referencing the seabed topographic depth measurement based on the regional lowest sea level model in coastal areas of Vietnam.

4. Research methodology

Collecting data and documents method; synthesis methods, Analysis and comparison method; Modeling method; Theoretical method; Mathematical method; Informatics method; Professional method; Experimental calculation method.

5. The scientific and practical significance of the thesis

5.1. Scientific significance

(1) Establishing a scientific basis for the application GNSS RTK technology in hydrographic surveying for maritime safety in Vietnam's coastal waters; (2) Proposing a method to use the water level elevation calculated from the MIKE 21 FM model to correct the influence of tides in the seabed topographic depth measurement value and refer to the seabed topographic depth measurement based on the regional lowest sea level model.

5.2. Practical significance

(1) Research, establish a scientific basis and prove by experiment for the application of GNSS CORS RTK technology in hydrographic survey for maritime safety in Vietnam's coastal waters; (2) Building a scientific and practical basis for the application of the MIKE 21 FM model to serve to correct the influence of tides in the seabed topographic depth measurements instead of the water level monitoring data at the coastal tide stations; (3) Building a scientific basis for the reference of the seabed depth based on the LSS model to

ensure uniform accuracy in the waters of Vietnam; (4) The research results of the thesis have good reference value in theory and practice for the management agencies in researching and promulgating technical regulations on mathematical processing referencing the seabed topographic depth measurement based on the regional lowest sea level model and building a unified chart database on Vietnam's coastal waters.

6. Theoretical points to be defended

The first theoretical point: The experimental calculation results in the thesis have confirmed that it is possible to use the GNSS CORS RTK method to integrate with the echo sounder technology in hydrographic survey for maritime safety in Vietnam's coastal waters.

The second theoretical point: The water level determined from the MIKE21 FM model fully meets the technical standards to correct the influence of the seabed topographic depth measurement to establish nautical charts and shipping channel topographic plans for maritime safety in Vietnam's coastal areas.

The third theoretical point: Referring to the seabed topographic depth based on the MBTNKV170 model completely meets the technical requirements for establishing nautical charts and topographic plan for maritime safety and is an important mathematical basis for creating a scientific basis for establishing a unified chart database on Vietnam's coastal.

7. New points of the thesis

(1) Confirming that the GNSS CORS RTK technology fully meets the requirements for accuracy of determining the coordinates of the ground position and can be used to integrate with the echo sounder technology in hydrographic survey for maritime safety in Vietnam's coastal waters;

(2) Proposing a method to determine the water level from the MIKE21 FM model to correct the influence of the seabed topographic depth measurement in Vietnam's coastal areas;

(3) Proposing a method of referring to the seabed topographic depth based on the MBTNKV170 model in mathematical processing of the seabed topographic depth measurement data to establish the nautical charts and topographic plan for maritime safety.

8. Structure and contents of the thesis

The thesis consists of three parts: introduction, four chapters, conclusion.

Chapter 1. OVERVIEW OF RESEARCH ON HYDROGRAPHIC

SURVEYING FOR MARITIME SAFETY

This chapter covers the following main topics:

- Introduce the tasks, the technical standards in the world and in the country currently used in the hydrographic survey for maritime safety; Selection of technical criteria for hydrographic survey for maritime safety the coastal areas, navigation channels and water areas.

Table 1.9- Selection of technical criteria for hydrographic survey for maritime safety

Criteria	Surveying Order			
	Special Order		Order 1	
Area description	-The first survey to serve maritime notification of the following areas: harbours, berthing areas and critical areas of fairways and channels, areas for anchoring, transshipment, typhoon shelter, pilot station, quarantine, routes new navigational channels. -Surveying, acceptance, and dredging works to renovate and upgrade the navigation depth for the above areas. - Areas where there is important navigational areas with strict minimum underkeel clearance		Periodic survey for maritime notification of the following areas: port tanks (docking area, turning area), navigation channels with small pilot feet, areas for mooring, transshipment, typhoon shelter, pilot station, quarantine, navigational routes with a depth of less than or equal to 40m.	
Horizontal Accuracy (95% Confidence Level)	1m		2m	
Depth Accuracy for Reduced Depths (95% Confidence Level)	a = 0,15m b = 0,0075		a = 0,25m b = 0,0075	
Feature Detection	Cubic features ≥ 1m		Cubic features ≥ 2m	
The maximum distance between two successive measuring lines and point density				
- The maximum distance between two successive measuring lines	Scale	Distance	Scale	Distance
	1/200	2 m	1/2000	20 m
	1/500	5 m	1/5000	50m
	1/1000	10 m	1/10000	100m
- The maximum distance between two points on a measuring line	1/200	2 m	1/2000	10 m
	1/500	5 m	1/5000	25m
	1/1000	5 m	1/10000	50m

- Effects of natural conditions such as topography, waves, wind, currents, tides,... of Vietnam's coastal sea areas on hydrographic survey for maritime safety;

- An overview of the studies carried out in Vietnam and around the world on the application of real-time dynamic GNSS technology in hydrographic survey, on the construction of sea surface models, on the research results using the model. MIKE 21 FM. From there, identify issues those need further research:

(1) Research and application of GNSS CORS RTK technology integrated with echo sounding data in hydrographic survey for maritime safety in Vietnam conditions.

(2) Research and propose a method to use the water level elevation calculated according to the MIKE 21 FM model to correct the influence of tides in the depth measurements of the seabed topography.

(3) Research, propose methods and establish a reference formula for seabed topographic depth observation based on the LSS in the waters of Vietnam.

CHAPTER 2. RESEARCH AND APPLICATION OF GNSS CORS RTK TECHNOLOGY IN HYDROGRAPHIC SURVEY FOR MARITIME SAFETY ON COASTAL SEA OF VIETNAM

2.1. Real-Time Kinematic GNSS technology

The measurement principle of GNSS Base RTK and GNSS CORS RTK are both based on the principle of second-differential dynamic relative positioning. The most suitable measurement method for hydrographic work is continuous kinematic measurement. The basic components of the CORS station system include: Reference station system; Master station (Central processing and control station) and user. The schematic diagram of the system is shown in Fig 2.2.

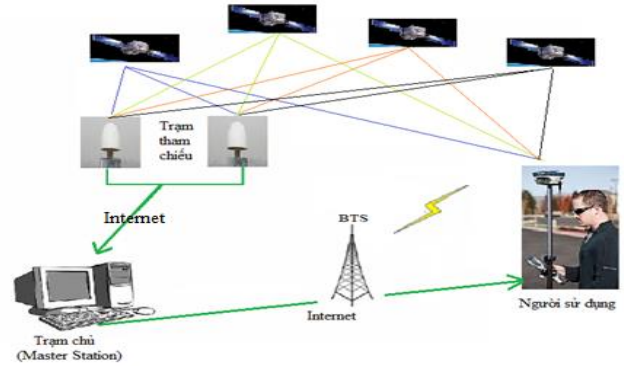

Figure 2.2- Overview diagram of GNSS CORS station system

2.1.3. The applicability of GNSS CORS RTK in hydrographic survey for

maritime safety in coastal waters of Vietnam

2.1.3.1. Network infrastructure of CORS stations in Vietnam

GNSS CORS station system of Vietnam Department of Surveying, Mapping and Geographic Information: 65 GNSS CORS stations, connected to the national coordinate grid system (VN2000) and the international coordinate system (ITRF), with number geoid model correction inland area. Provides Real-Time Kinematic measurement of both network CORS stations and single CORS stations. In addition to the state GNSS CORS station system, private units have invested in building and put into use nearly 300 GNSS CORS stations, the GNSS CORS stations have connected to the national coordinate grid system (VN2000), providing single station CORS real-time dynamic measurement service.

2.1.3.2. Research and application of GNSS CORS RTK technology for hydrographic work in service of marine geometries in coastal waters of Vietnam

(1) The network of GNSS CORS stations along the coast of Vietnam

The total number of GNSS CORS stations along the coast of Vietnam is about 65 built by the State and private enterprises. The range of single CORS stations in coastal areas is about 25-30km.

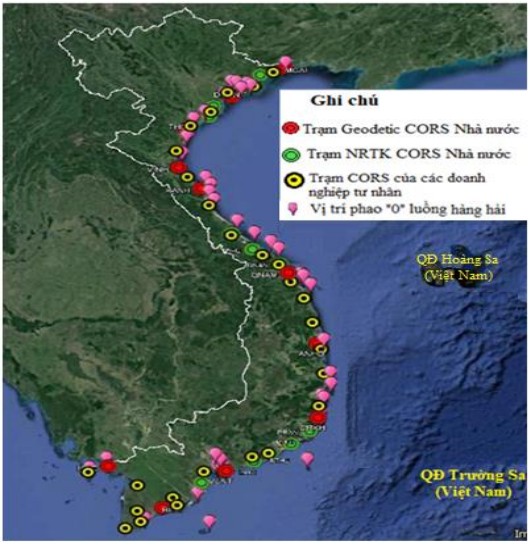

Figure 2.7- Coastal CORS GNSS station and buoy position “0” navigation channel

(2) BTS telecommunications infrastructure

There are 3 major carriers: VNPT, Viettel and MobiFone. These operators

have invested in upgrading and developing new fiber optic cables and BTS stations to provide high quality services. In the coastal area of Vietnam, the coverage of the radius is about 30-50km [94].

(3) GNSS receiver:

The modern GNSS receivers of famous brands such as: Trimble, Topcon, Sokkia, Leica, Kolida, CHC, Hi-Target, ... receive multi-system satellite signals, all capable of receiving and transmitting Radio and Bluetooth waves, Wifi, 2G/3G/4G.

(4) Scope of hydrographic survey for maritime safety

From buoy number "0" back to the mainland, the pilot pick-up and drop-off area, mooring boats, ...

On the infrastructure of GNSS CORS stations, BTS stations and the range of stations and scope of research, the researcher found that: it is possible to use GNSS CORS technology in survey for maritime safety.

2.2. Integrating GNSS CORS RTK with echo sounding technology for underwater topographic survey for maritime safety

Connect the equipment on the measuring vessel according to the following diagram:

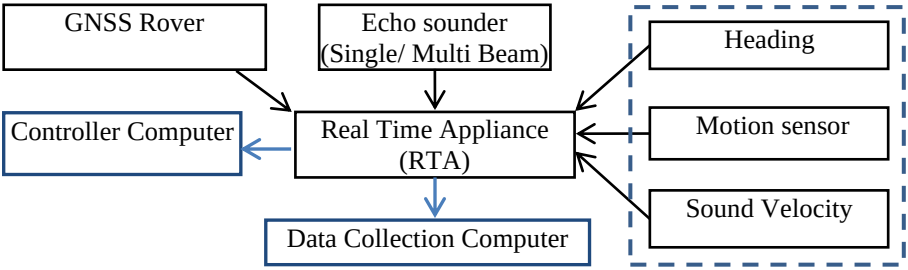

Figure 2.8- Connection diagram of echo sounding devices

After connecting the equipment on the measuring vessel, establishing the mathematical basis and the depth measurement parameters, conducting depth measurement along the designed route. Depending on whether the measurement area is within the CORS station network area, use the CORS single station service or the network CORS service.

The measured data obtained is the coordinates in the WGS84 system or VN-2000 coordinate system (If you set up the parameter transferred from WGS system and VN-2000 system), the geodetic height of the water surface and the

depth measured from the waters surface to the seabed depth ($D^{do} = D + d_r$) of measurement point i.

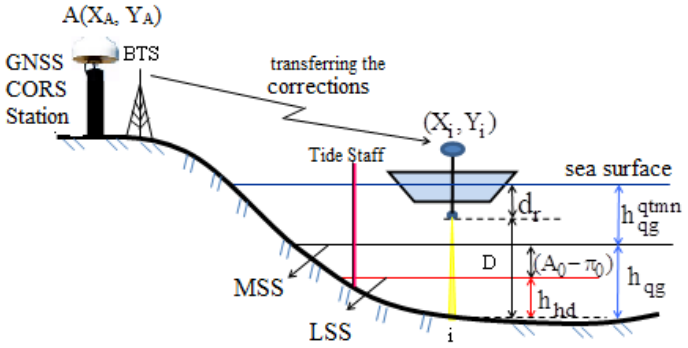

Figure 2.11- Principle of echo sounder combined with GNSS CORS RTK technology

Conclusion Chapter 2

In chapter 2, the PhD student has studied the principles of GNSS Base RTK and GNSS CORS RTK measurement, applied to improve coordinate accuracy in hydrographic survey for maritime safety of Vietnam's coastal waters. Based on the analysis of collected data about the infrastructure of CORS stations, BTS stations and the operating range of stations and the scope of the research topic, the PhD student has found that:

(1) GNSS Base RTK technology has been studied in detail in theory and effectively applied in practice, especially hydrographic survey for maritime safety.

(2) The density of CORS GNSS stations in the territory of Vietnam is relatively thick, the data is received at different frequencies, so if it can be applied to hydrographic survey, it will save time and money. GNSS CORS station technology can be used in conjunction with echo sounder technology in hydrographic survey for maritime safety.

CHAPTER 3. MATHEMATICAL PROCESSING OF THE SEABED TOPOGRAPHIC DEPTH MEASUREMENT DATA IN HYDROGRAPHIC SURVEY FOR MARITIME SAFETY

3.1. Using some sea surface models in hydrographic survey for maritime safety

3.1.1. Mean sea surface model and lowest sea surface model

The Mean sea surface model is built by using the DTU10MDT model combined with the mean sea surface height at the tide stations along the coast of Vietnam using ArcGis software. The DTU10 MDT model in the Non – Tide

System is converted to the national height system (Hon Dau) in the mean tide system according to the formula [16]:

$$\overline{\mathrm{MDTVN_m}} = \overline{\mathrm{MDT_n}} - 0.890\mathrm{m} + \delta\mathrm{MDT_{n-m}} + \begin{cases} 0 & \text{when } B \geq 19^0 57' \\ -0.318\mathrm{m} & \text{when } B < 19^0 57' \end{cases} \quad (3.11)$$

The MBTBKV98 model was established using the Loang Algorithm in ArcGis software on the basis of using a combination of the data of the DTU10MDT model (after transfering from the global height system (based on the EGM2008 model) in the non-Tide system to the Hon Dau height system in the mean tidal system according to formula (3.11)) and the mean sea surface at 98 tide stations along the coast and on some islands of Vietnam [38]. (Figure 3.1)

The MBTNKV170 model was established based on the height of the lowest sea surface at 170 tide stations along the coast and on some Vietnamese islands using ArcGis software [38]. (Figure 3.2)

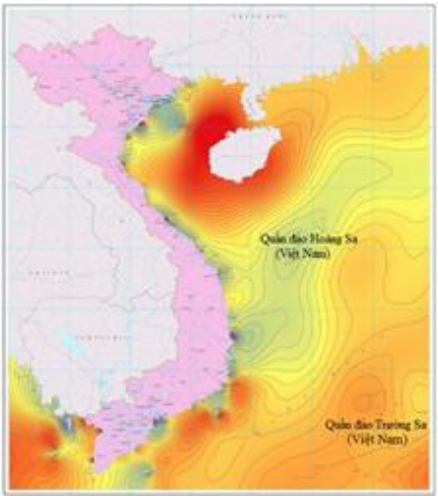

Figure 3.1- MBTBKV98 model of Vietnam's waters

Figure 3.2- MBTNKV170 model of Vietnam's waters

According to the evaluation in the document [38], the accuracy difference between MBTBKV98 model and MBTNKV170 model reached ±0.128m.

The MBTBKV98 model and MBTNKV170 model will be used to establish a reference method for water level observation and depth's seabed topographic measurement observation in hydrographic survey for maritime safety in Vietnam's coastal waters and maritime fairway system.

3.1.2. Using the MIKE 21 Flow Model to determine the water level

MIKE 21 Flow Model FM is a software package within the MIKE Software Suite. MIKE 21 Flow Model FM is a 2D surface flow model, which is applied to simulate hydraulic processes and environmental phenomena in lakes, rivers, estuaries, bays, coastal waters and other coastal areas waters. The model includes modules: Hydrodynamic Module, Transport Module, MIKE ECO Lab/Oil Spill Module, Mud Transport Module, Particle Tracking Module and Sand Transport Module. The Hydrodynamic Module is the basic computational component of the entire MIKE 21 Flow Model FM modelling system providing the hydrodynamic basis for the entire MIKE system, providing hydraulic calculations for other modules [84], [86], [96]. The MIKE21 FM model will be used to determine the water level height at the location of the depth measurement points to correct the influence of tides in the depth's seabed topographic measurements, replacing the water level observed at the tidal gauge station temporary shore.

3.1.2.3. Building the problem of calculating water level using MIKE21 FM model

a. Input data

- Depth's seabed topographic of the experimental area (using the seabed topographic map including the contour lines) the tidal height calculation area according to the National Height System.

- Coastline coordinates.

- Data at the edges (from three or more edges)

b. Creating the mesh and boundary conditions

- The mesh is created with MIKE21 FM software. Using the Triangular or quadrilateral mesh. Use a structured or unstructured grid depending on the tidal properties, the complexity of the terrain, and the accuracy of the tidal height determination at the mesh nodes.

- The water level height at the liquid boundary uses the water level observed at the Tide station or uses the harmonic constant set available in the model.

- The water level calculation model of the area is created with a suitable level according to the Nash - Sutcliffe criteria [82] with a good level or higher to be used to calculate water level.

3.2. Referencing the water level observation

In the establishing of nautical chart and maritime fairway plan, the seabed

topographic depth measurement data which is referenced based on the lowest sea surface depth at the coastal tide station. This regulation serves two purposes:

-Reference measurement depths from the water surface to the seabed due to the influence of the tides on the lowest sea surface based on the water level observations at the temporary coastal tide station.

- Referrcing seabed topographic height to lowest sea surface [22].

In fact, the water level observations that must first be referenced based on the mean sea surface at the tide station and then be referenced based on the lowest sea surface by oceanographic methods, while the mean sea surface height is determined by the geodetic method or oceanographic method.

Because the mean of the sea surface and the lowest sea surface in different seas are different, the next content of the thesis will study the reference method for the water level observations (Figure 3.3) based on the sea surface models and using water level heights are determined from the MIKE21 FM model to replace the water level observations at the coastal tide stations.

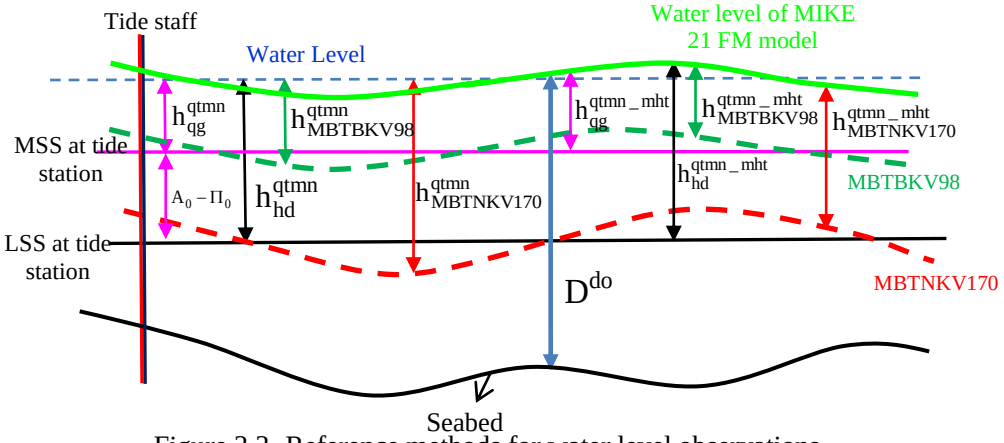

Figure 3.3- Reference methods for water level observations

3.2.1. Referring water level observations based on the mean sea surface and the lowest surface at the coastal tide gauge station

Water level heights are referenced based on the mean sea surface at the tide station according to the formula (Figure 3.3):

$$h_{qg}^{qtmn} = h_{0-tn}^{qtmn} + h_{qg}^{0-tn} \qquad (3.18)$$

The Lowest astronomical tidal level heights that are calculated based on the waters level in the mean sea surface and the difference between the mean sea surface and the lowest astronomical tidal level height $(A0 - \pi 0)$ is:

$$h_{hd}^{qtmn} = h_{qg}^{qtmn} - (A0 - \pi 0) \quad (3.19)$$

3.2.2. Referring water level observations based on sea surface models

Because the mean sea surface (or lowest sea surface) at the depth measurement location is not the same as the mean sea surface (or lowest sea surface) at the tide station, the water level observations and the seabed topographic depth observations (at the same time) are referenced based on the the mean sea surface (or lowest sea surface) at the positioning to measure depth on the basis of using Regional mean sea surface model -MBTBKV98 (or Regional lowest sea surface model -MBTNKV170).

3.2.2.1. ***Referring water level observations based on*** *MBTBKV98 model*

Water level heights are referenced based on *MBTBKV98 model* according to the formula (Figure 3.3):

$$h_{MBTBKV98}^{qtmn} = h_{qg}^{qtmn} - h_{MBTBKV98}^{dc} \quad (3.20)$$

3.2.2.2. Referring water level observations based on MBTNKV170

Water level heights are referenced based on MBTNKV170 *model* according to the formula (Figure 3.3):

$$h_{MBTNKV170}^{qtmn} = h_{hd}^{qtmn} - h_{MBTNKV170}^{dc} \quad (3.21)$$

3.2.3. Referring water level observations of MIKE21 FM model

3.2.3.1. Referring water level observations of MIKE21 FM model based on MBTBKV98 model

The water level is determined from the reference MIKE21 FM model based on the MBTBKV98 model according to the formula (Figure 3.3):

$$h_{MBTBKV98}^{qtmn\_mht} = h_{qg}^{qtmn\_mht} - h_{MBTBKV98}^{dc} \quad (3.22)$$

3.2.3.2. Referring water level observations of MIKE 21 FM model based on MBTNKV170 model

The water level is determined from the reference MIKE 21 FM model based on the MBTNKV170 model according to the formula (Figure 3.3):

$$h_{MBTNKV170}^{qtmn\_mht} = h_{qg}^{qtmn\_mht} - h_{MBTNKV170}^{dc} \quad (3.23)$$

3.3. *Referring* seabed topographic Depths

Using the water level observations data at the tide station and the water level data according to the MIKE 21 FM model, which is referenced based on the MSS at the tide station and the MBTBKV98 model and MBTNKV170 model to calibrate for the seabed topographic Depths. Figure 3.8 shows the results of referencing the the seabed topographic Depths by different methods.

3.3.1. Referring seabed topographic depth based on LSS at the coastal tide station

Seabed topographic depth is referred to LSS at the coastal tide station is calculated according to the formula (Figure 3.8)

$$h_{hd}^{do} = h_{hd}^{qtmn} - D^{do} \quad (3.24)$$

3.3.2. Referring seabed topographic depth based on MBTNKV170 model

Seabed topographic depth is referred to MBTNKV170 is calculated according to the formula (Figure 3.8)

$$h_{MBTNKV170}^{do} = h_{MBTNKV170}^{qtmn} - D^{do} \quad (3.25)$$

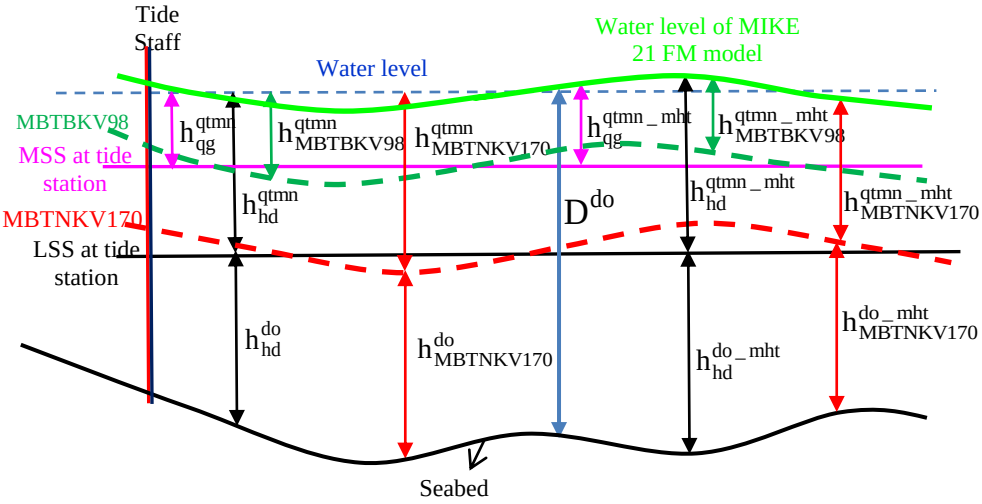

Figure 3.8- Reference methods for seabed topographic depth

3.3.3. Referring seabed topographic depth based on LSS and MBTNKV170 model according to water level data of MIKE21 FM model

3.3.3.1. Referring seabed topographic depth based on LSS according to water level data of MIKE 21 FM model

Referring seabed topographic depth based on LSS according to water level data of MIKE 21 FM model is calculated by the formula (Figure 3.8)

$$h_{hd}^{do\_mht} = h_{hd}^{qtmn\_mht} - D^{do} \quad (3.26)$$

3.3.3.2. Referring seabed topographic depth based on MBTNKV170 model according to water level data of MIKE 21 FM model

Referring seabed topographic depth based on MBTNKV170 model according to water level data of MIKE 21 FM model is calculated by the formula (Figure 3.8)

$$h_{MBTNKV170}^{do\_mht} = h_{MBTNKV170}^{qtmn\_mht} - D^{do} \quad (3.27)$$

Conclusion of chapter 3

Based on the scientific basis and methods developed in Chapter 3, the following conclusions can be drawn:

(1) Regarding the construction method of sea surface models:

+ Presenting the theoretical basis and data sources to build the model of MBTBKV98 area and MBTNKV170 area model.

+ Review, evaluate and select MBTBKV98 model and MBTNKV170 model to develop reference methods for water level observations and water level of MIKE21 FM model based on sea surface models

(2) Regarding the reference to the water level observations:

+ Comprehensively review the method of reference to the water level observations based on the MSS and LSS at the coastal tide station, based on the MBTBKV98 model and the MBTNKV170 model.

+ Presenting the theoretical basis and method of exploiting the water level of the MIKE 21 FM model and using it to replace the observed water level at the coastal tide station.

(3) Regarding the reference to the seabed topographic depth based on the lowest astronomical tide level:

+ Develop formulas to refer to water level according to MIKE21 FM model based on LSS at tide station and on MBTNKV170 model.

+ Development of formulas to refer to the seabed topographic depth based on the MBTNKV170 model.

CHAPTER 4. EXPERIMENTAL MEASUREMENT AND RESULTS PROCESSING DATA

4.1. Experimental content

(1) Measure GNSS using GNSS CORS RTK and GNSS Base RTK technology in Hai Duong and Hai Phong, and evaluate the accuracy between measurement options.

(2) Measure GNSS using GNSS CORS RTK and GNSS Base RTK technology integrated with echo sounder survey seabed topographic depth, measuring water level observations to correct depth measurements, and evaluate accuracy between two measurement options when depth measuring underwater;

(3) Processing GNSS measurement data according to the measurement plans, processing and integrating GNSS measurement data with depth measurement data;

(4) Adjusting the water level into the seabed topographic depth based on the water level observations at the coastal tide station and based on the water level data according to the MIKE21 FM model;

(5) Referencing the seabed topographic depth based on the LSS at the coastal tide station and the MBTNKV170 model.

4.2. Experimental assessment of accuracy of GNSS CORS RTK and GNSS Base RTK measurements for the establishment of nautical charts, seabed topographic in coastal water and shipping channels

4.2.1. Experiment to evaluate the accuracy of measuring GNSS CORS RTK and GNSS Base RTK on land

4.2.1.1. Experiment at Vietnam Maritime University and Dinh Vu port

To confirm the accuracy of GNSS RTK measurement, the PhD student conducted an experiment to measure 17 benchmarks have known coordinates according to 3 options:

- Option 1: Measure GNSS CORS RTK using CORS HPTP station in Hai Phong, the distance from the furthest point of the experimental area to the CORS station is 10.03km.

- Option 2: Measure GNSS CORS RTK using CORS HDTP station in Hai Duong, the distance from the furthest point of the experimental area to the CORS station is 53,45km;

- Option 3: Measure GNSS Base RTK (using Internet measurement method (3G)) with Base station located at the base cadastral 118518, the distance from the furthest point of the experimental area to Base station is 11.4km.

The coordinate deviation comparison results are evaluated as follows:

- The mean square error of the location measured by GNSS CORS RTK technology (the distance from the furthest point of the experimental area to the CORS station about 11km) is: ± 0.018 (m)

- The mean square error of the position measured by GNSS CORS RTK technology, (the distance from the furthest point of the experimental area to the CORS station about 54km) is: ± 0.050 (m)

- The mean square error of the location measured by GNSS Base RTK technology (the distance from the furthest point of the experimental area to Base station about 11km) is: ± 0.022 (m)

4.2.1.2. Experiment at Lach Huyen port

Experimenting to measure 5 benchmarks have known coordinates in Lach Huyen port, according to 2 options:

- Option 1: Measure GNSS CORS RTK using CORS DSON station in Hai Phong, the distance from the furthest point of the experimental area to the CORS station is 17.36km.

- Option 2: Measure GNSS Base RTK (using Internet measurement method (3G)) with Base station located at HP.B-1 benchmark, the distance from the furthest point of the experimental area to Base station is 1.13 km .

The coordinate deviation comparison results are evaluated as follows:

- The mean square error of the location measured by GNSS CORS RTK technology (the distance from the furthest point of the experimental area to the CORS station about 18km) is: ± 0.019 (m)

- The mean square error of the location measured by GNSS Base RTK technology (the distance from the furthest point of the experimental area to Base station about 2km) is: ± 0.021 (m)

From the results of 2 experiments on land shows:

- The measuring area is about 18km from the GNSS CORS station, about 12km from the Base station, the Hozizontal accuracy of the two GNSS CORS RTK and GNSS Base RTK measurement options are equivalent, at ±0.022m. Therefore, it is possible to use GNSS CORS RTK technology in hydrographic survey for maritime safety like GNSS Base RTK technology.

- The measuring area is about 54km from the GNSS CORS station, the hozizontal accuracy of the measured point by GNSS CORS technology is ±0.050m, compared with the current hydrographic technical standard TCVN 10336-2015 (Table 1.9), showing that there is a complete can use GNSS CORS RTK technology in hydrographic survey.

4.2.2. Experiment to evaluate the accuracy of measuring GNSS CORS RTK method and GNSS Base RTK method when integrated with echo sounders.

4.2.2.1. Measurement plan

Experimental measurement at Lach Huyen channel - Hai Phong using 2 methods of measuring GNSS RTK according to two options:

- Option 1: Measure GNSS CORS RTK using CORS DSON station (Do Son - Hai Phong) of the Ministry of Natural Resources and Environment

- Option 2: Measure GNSS Base RTK (using Internet measurement method (3G)) with Base station located at HP.B-1 benchmark.

4.2.2.4. Processing measurement data

From the measured data (coordinates, depth and water level data), conduct depth measurement data processing: from the depth measurement data file has

been calibrated data from motion sensor devices, calibrated water level elevation and discard poor quality readings. Measurement results are shown in Appendix 1 and Appendix 2

4.2.2.5. Evaluate the accuracy of coordinate measurement results

The results of the accuracy assessment are shown in Table 4.9.

Table 4.9- Results of assessment of accuracy of coordinate deviation between GNSS CORS RTK and GNSS Base RTK measurement plans of Lach Huyen navigational channel

STT	$X^{(1)}$ (m)	$Y^{(1)}$ (m)	$X^{(2)}$trans (m)	$Y^{(2)}$ trans (m)	d_x (m)	d'_x (m)	$d'_x.d'_x$ (m^2)	dy (m)	dy.dy (m^2)
1	2293621.42	626316.29	2293620.89	626316.71	0.53	0.36	0.13	-0.42	0.1745
2	2293614.92	626308.83	2293615.36	626308.73	-0.44	-0.60	0.36	0.10	0.0096
3	2293608.62	626301.09	2293608.10	626301.49	0.52	0.36	0.13	-0.40	0.1603
4	2293602.34	626293.23	2293601.86	626293.68	0.48	0.32	0.10	-0.45	0.1986
5	2293596.34	626285.27	2293595.81	626285.66	0.53	0.36	0.13	-0.39	0.1552
...	...	...	...	...	...	...	...	...	...
11135	2293655.43	626265.82	2293655.17	626266.15	0.26	0.10	0.01	-0.33	0.1063
11136	2293661.7	626273.69	2293661.43	626274.12	0.27	0.11	0.01	-0.43	0.1875
11137	2293668.3	626281.21	2293668.04	626281.54	0.26	0.10	0.01	-0.33	0.1063
11138	2293674.62	626288.98	2293674.35	626289.38	0.27	0.11	0.01	-0.40	0.1580
11139	2293679.9	626297.58	2293679.63	626297.94	0.27	0.10	0.01	-0.36	0.1295
11140	2293684.69	626306.35	2293685.06	626305.74	-0.37	-0.53	0.28	0.61	0.3734

Mean square error of point position of each measured value $m_P = \pm 0.45$m. According to the technical standard, the ground accuracy is 1m (Table 1.9), the above error satisfies the requirements of special class survey. Therefore, the above two methods of measuring GNSS RTK completely meet the requirements of hydrographic survey for maritime safety in Vietnam.

4.3 Establishing a model to calculate the water level by MIKE 21 FM for the experimental area

4.3.1. Data for model building:

- Using Lach Huyen channel measurement data in Hai Phong sea area measured on December 21- 22th, 2019.

- Input data:

+ Using seabed topographic depths of seabed topographic map in the experimental area (scale 1/50000) was published by the Center for Geodesy and Mapping, the General Administration of Seas and Islands of Vietnam in 2003 -2005

+ Using depths of nautical chart, scale 1/100.000 was published by the Hydrographic and Oceangraphic Department in the years 2006-2009 and was converted to seabed topographic depths.

+ Using the coastline of the MBTNKV170 model.

+ Coordinates, heights and water level observations data at the border is provided by the oceanographic center -Vietnam Administration of Seas and Island.

4.3.2. Building the problem of calculating water level in Hai Phong sea area

4.3.2.1 Creating the mesh and boundary conditions

The mesh is developed for the Hai Phong channel area is a triangular grid with the highest resolution of 20 meters and gradually spreading out to about 300 meters offshore. The grid consists of 4 liquid boundaries, of which 2 are sea boundaries (boundary 1: from Cat Ba to Van Uc area, boundary 2: from Hoang Tan commune to Hon Cai Be), two river border at Cua Cam hydrological station (on Cam River) and Do Nghi hydrological station (on Da Bach river).

+ The measured water levels at the two sea boundaries are the estimated tidal data based on the set of tidal harmonic constants in the MIKE 21 FM model and are converted to the national height system according to the Hon Dau tidal station data;

+ The water levels at the two stations Do Nghi and Cua Cam are the water level data that has been transferred from the two tide stations Do Nghi and Cua Cam to the national height system;

Using the MIKE 21 FM model to create the mesh and get the results as shown in Figure 4.8.

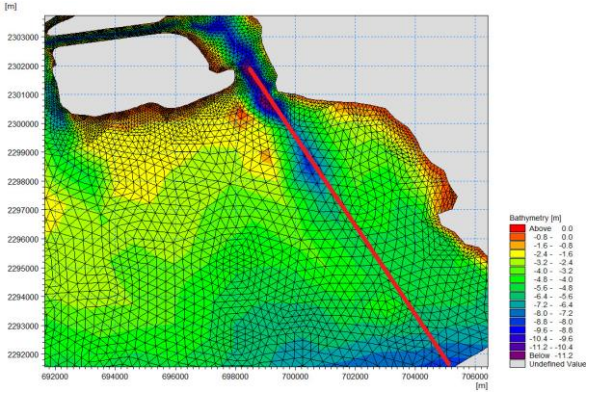

Figure 4.9- The mesh for water level model in Hai Phong channel area

The model is carefully corrected and tested based on actual measured water level data in Hai Phong sea area. The results of evaluating the accuracy of the model compared with the real data measured by the Nash - Sutcliffe criterion is good quality. Thus, the tidal forecasting model can be used to extract water level data to correct the seabed topographic depths for Lach Huyen channel to replace

the water level measurement data at the temporary coastal tide station.

4.4. Experimental calculation of reference water level measurement based on LSS at tide station and based on MBTBKV98 model and MBTNKV170 model

4.4.1. Data for experimental calculations

To see the advantages of referencing water level measurements based on sea surface models, the PhD student used water level measurement data at Lach Huyen port tide station, water level data according to MIKE 21 FM model to correcting the depth measurements of Lach Huyen channel in Hai Phong area.

4.4.2. Experimental calculation

Conduct experimental calculations according to the method developed in sections 3.2 and 3.3 to refer to the water level observation for the following four cases:

+Referering water level observation based on the LSS at the temporary coastal tide station;

+ Referering water level observation based on MBTBKV98 model.

+ Referering water level observation based on MBTNKV170 model.

+ Reference water level according to MIKE 21 FM model based on MSS and LSS at tidal station and based on MBTBKV98 model and MBTNKV170 model.

Calculation results are summarized and statistical in Table 4.11

Table 4.11- Referering water level observation and water level using MIKE 21 FM model

STT	X (m)	Y (m)	Time (h:m:s)	Depth (m)	water level obs base on MSS at tide station (m)	water level obs base on LSS at tide station (m)	Height of MBTBKV98 model (m)	Height of MBTNKV170 model (m)	water level obs base on MBTBKV98 model (m)	water level obs base on MBTNKV170 model (m)	water level according to MIKE 21 FM base on MSS according to height datum (m)	water level according to MIKE 21 FM base on LSS at tide station (m)	water level according to MIKE 21 FM base on MBTBKV98 model (m)	water level according to MIKE 21 FM base on MBTNKV170 model (m)
1	2293621	626316	7:33:42	11.34	0.71	2.84	-0.04	-2.16	0.75	2.87	0.61	2.74	0.65	2.77
2	2293615	626309	7:33:47	11.74	0.71	2.84	-0.04	-2.16	0.75	2.87	0.61	2.74	0.65	2.77
3	2293609	626301	7:33:48	12.04	0.71	2.84	-0.04	-2.16	0.75	2.87	0.61	2.74	0.65	2.77
4	2293602	626293	7:33:51	12.04	0.71	2.84	-0.04	-2.16	0.75	2.87	0.61	2.74	0.65	2.77
5	2293596	626285	7:33:54	12.04	0.71	2.84	-0.04	-2.16	0.75	2.87	0.61	2.74	0.65	2.77
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
11136	2293662	626274	17:17:48	11.01	0.08	2.21	-0.04	-2.16	0.12	2.24	-0.12	2.01	-0.07	2.05
11137	2293668	626281	17:17:51	11.01	0.08	2.21	-0.04	-2.16	0.12	2.24	-0.12	2.01	-0.07	2.05
11138	2293675	626289	17:17:53	10.51	0.08	2.21	-0.04	-2.16	0.12	2.24	-0.12	2.01	-0.07	2.05
11139	2293680	626298	17:17:57	9.71	0.08	2.21	-0.04	-2.16	0.12	2.24	-0.12	2.01	-0.07	2.05
11140	2293685	626306	17:18:00	6.81	0.08	2.21	-0.04	-2.16	0.12	2.24	-0.12	2.01	-0.08	2.05

4.5. Experimental calculation of the referring seabed topographic depth

4.5.1. Experimental calculation of the referring seabed topographic depth based on MSS at tide station and MBTNKV170 model

Similar to the reference for water level observation, the seabed topographic depth is also referenced for four cases:

+Referering seabed topographic depths based on the LSS according to water level observation at the temporary coastal tide station;

+ Referering seabed topographic depths based on MBTNKV170 model according to water level observation at the temporary coastal tide station.

+ Referering seabed topographic depth based on MSS according to water level data of tidal calculation model using MIKE 21 FM model

+ Referering seabed topographic depths based on MBTNKV170 model according to water level data of MIKE 21 FM model

Calculation results are summarized and statistical in Table 4.12

Table 4.12- Referering seabed topographic depth according to water level observation and water level data of MIKE 21 FM model

STT	X (m)	Y (m)	Time (h:m:s)	Depth (m)	water level obs base on LSS at tide station (m)	Depth base On LSS at tide station (m)	water level obs base on MBTN KV170 Model (m)	Dept base on MBTN KV170 Model (m)	water level according to MIKE 21 FM base on LSS at tide station (m) (m)	Depth base on LSS according to MIKE 21 FM (m)	water level according to MIKE 21 FM base on MBTN KV170 model (m)	Depth base on MBTN KV170 according to MIKE 21 FM (m)	d1 (m)	d2 (m)	d3 (m)
1	2293621	626316	7:33:42	11.34	2.84	-8.50	2.87	-8.46	2.74	-8.60	2.77	-8.57	-0.035	0.101	0.066
2	2293615	626309	7:33:47	11.74	2.84	-8.90	2.87	-8.86	2.74	-9.00	2.77	-8.97	-0.035	0.101	0.066
3	2293609	626301	7:33:48	12.04	2.84	-9.20	2.87	-9.16	2.74	-9.30	2.77	-9.27	-0.035	0.101	0.066
4	2293602	626293	7:33:51	12.04	2.84	-9.20	2.87	-9.16	2.74	-9.30	2.77	-9.27	-0.035	0.101	0.066
5	2293596	626285	7:33:54	12.04	2.84	-9.20	2.87	-9.16	2.74	-9.30	2.77	-9.27	-0.035	0.101	0.066
6	2293590	626277	7:33:57	12.94	2.84	-10.10	2.87	-10.06	2.74	-10.20	2.77	-10.17	-0.035	0.101	0.066
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
11134	2293649	626258	17:17:41	11.41	2.21	-9.20	2.24	-9.17	2.01	-9.40	2.05	-9.37	-0.035	0.197	0.162
11135	2293655	626266	17:17:45	11.11	2.21	-8.90	2.24	-8.87	2.01	-9.10	2.05	-9.07	-0.035	0.197	0.162
11136	2293662	626274	17:17:48	11.01	2.21	-8.80	2.24	-8.77	2.01	-9.00	2.05	-8.97	-0.035	0.197	0.162
11137	2293668	626281	17:17:51	11.01	2.21	-8.80	2.24	-8.77	2.01	-9.00	2.05	-8.97	-0.035	0.197	0.162
11138	2293675	626289	17:17:53	10.51	2.21	-8.30	2.24	-8.27	2.01	-8.50	2.05	-8.47	-0.035	0.197	0.162
11139	2293680	626298	17:17:57	9.71	2.21	-7.50	2.24	-7.47	2.01	-7.70	2.05	-7.67	-0.035	0.197	0.162
11140	2293685	626306	17:18:00	6.81	2.21	-4.60	2.24	-4.57	2.01	-4.80	2.05	-4.77	-0.035	0.199	0.164
												∑=	-802.15	1022.44	220.28
												m=	0.038	0.034	0.047

4.5.2. Accuracy rating

The accuracy of the reference seabed topographic depth by different

methods is evaluated according to the reference depth based on the LSS at the tide station.

- Accuracy of the reference seabed topographic depth based on the LSS at the tide station according to the observed water level data $\left(h_{hd}^{do}\right)$ and the reference seabed topographic depth based on the MBTNKV170 model according to the observed water level data $\left(h_{MBTNKV170}^{do}\right)$:

$$m_h = \pm\sqrt{\frac{\left[d_h' \times d_h'\right]}{2\times(n-1)}} = \pm\sqrt{\frac{32.248}{2\times(11140-1)}} = \pm 0.038(m)$$

- Accuracy of the reference seabed topographic depth based on the LSS at the tide station according to the observed water level data $\left(h_{hd}^{do}\right)$ and the reference seabed topographic depth based on the LSS according to the water level data of the MIKE 21 FM model $\left(h_{hd}^{do\_mht}\right)$:

$$m_h = \pm\sqrt{\frac{\left[d_h' \times d_h'\right]}{2\times(n-1)}} = \pm\sqrt{\frac{25.913}{2\times(11140-1)}} = \pm 0.034(m)$$

- Accuracy of the reference seabed topographic depth based on the LSS at the tide station according to the observed water level data $\left(h_{hd}^{do}\right)$ and the reference seabed topographic depth based on the MBTNKV170 model according to the water level data of the MIKE 21 FM model $\left(h_{MBTNKV170}^{do\_mht}\right)$

$$m_h = \pm\sqrt{\frac{\left[d_h' \times d_h'\right]}{2\times(n-1)}} = \pm\sqrt{\frac{50.236}{2\times(11140-1)}} = \pm 0.047(m)$$

The occurrence of systematic errors in two ranges of reference measurements based on LSS at the tidal station and based on the MBTNKV170 model once again confirms that, using LSS at the coastal tide stations to refer to the seabed topographic depth measurements does not guarantee reliability.

From the experimental calculation results in this section, it is shown that:

- On the basis of the results of the assessment of the accuracy of the seabed topographic depth referenced based on the LSS according to the water level observation data at the temporary coastal tide station and the reference based on the sea surface models (the MBTBKV98 model and the MBTNKV170 model) shows that it is possible to use sea surface models to refer to the seabed topographic depth for the purpose of nautical charts and seabed topographic plans.

- The water level determined from the MIKE 21 FM model can completely replace the water level observation data at the temporary coastal tide station to refer to the seabed topographic depth.

Conclusion Chapter 4

From the experimental results in Chapter 4, some conclusions can be drawn as follows:

(1) Regarding the use of GNSS CORS RTK technology for maritime safety

- With the distance between the GNSS CORS station and the Rover up to 54 km, the accuracy of coordinates determination is ±0.05m, so it can be confirmed that: It is possible to use GNSS CORS RTK technology in the hydrographic survey of the coastal areas of Vietnam.

- Coordinates of geographical features at sea are determined with an accuracy of ±0.45m, so it can be confirmed that: GNSS CORS RTK technology completely meets the technical requirements for use in hydrographic survey for maritime safety.

(2) Using the water level data at the coastal tide station and the MIKE 21 FM model water level data to correct for the seabed topographic depth observation:

- Using MBTBKV98 model and MBTNKV170 model to refer to the water level data at the coastal tital station to the seabed topographic depth observation to match the natural surface of the sea.

- With an accuracy of ±0.047m, it can be confirmed that: The water level data calculated from the MIKE 21 FM model completely replaces the water level observation data at the coastal tide station to correct for the seabed topographic depth observation in hydrographic survey for maritime safety.

(3) Methods and reference formulas referering seabed topographic depth is developed by the thesis completely meet the technical requirements for the establishment of nautical charts and seabed topographic plans in hydrographic survey for maritime safety.

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

From the results of theoretical research and experimental measurements, the following conclusions can be drawn:

1. The GNSS CORS RTK method fully meets the requirements for horizontal accuracy according to current hydrographic survey standards. The results of experimental calculation and accuracy assessment have confirmed that the GNSS CORS RTK method can be used to integrate with echosounders equipment in hydrographic surveying for maritime safety.

2. The method of determining the water level from the MIKE 21 Flow Model FM is reliable. The experimental calculation results have confirmed that referring the seafloor depth measurements to tidal datums in hydrographic surveying for maritime safety using water levels determined from coastal tide stations can be replaced by water levels determined from the MIKE 21 Flow Model FM.

3. The method and the reference formulas for water level measurements and reduced bathymetric values referred to tidal datums based on a regional lowest sea surface model (MBTNKV170) completely developed by the thesis fulfill the technical requirements in terms of mathematical processing of the depth measurements. The results of experimental calculation and assessment of the reference depth accuracy based on Lowest Sea Surface at coastal tital stations and reference based on MBTNKV170 model confirmed that: The MBTNKV170 model can be used to establish sounding datums in hydrography for nautical charting in coastal waters and access navigation channels in Vietnam.

4. Referring to the seabed topographic measured depths to sounding datums based on a regional lowest sea surface model (MBTNKV170) will ensure reliable determination of the seafloor depths on the entire coastal area of Vietnam. The regional lowest sea surface model MBTNKV170 is an important mathematical basis for processing depth data for the establishment of nautical charts to ensure safety navigation and to build a unified national nautical information database in coastal water of Vietnam.

2. RECOMMENDATIONS

(1) The GNSS CORS RTK method fully meets the requirements for horizontal accuracy according to current hydrographic survey standards and the GNSS CORS RTK method can be used to integrate with echosounders equipment in hydrographic surveying to establish seabed topographic map. We respectfully request the Ministry of Transport, Vietnam Maritime Administration and agencies related to the field of hydrographic survey to study and supplement technical regulations to be applied in practice.

(2) Methods and formulas developed by the thesis to determine the water level based on the MIKE 21 FM model to correct the influence of tides in the depths observation and refer to the seabed topographic depth based on MBTNKV170 model meets the technical requirements for establishing nautical charts and plan on the coastal waters of Vietnam, ensuring uniform accuracy throughout the sea area and establishing a scientific basis for establishing a basic system unified national chart data on the coastal waters of Vietnam. In addition, using the method of referencing the seabed topographic depth based on the MBTNKV170 model will solve the problems of contiguous boundaries between the contiguous areas of the nautical chart, the plan created by different measurement and measurement units. We respectfully request the relevant authorities to research and organize the inspection and supplement of technical standards and regulations to soon be put into applied in practice.

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