On the Establishment Method of Marine Vertical Datum Seamless System

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Abstract: At present, all kinds of vertical datum can only suit partial sea so that it leads to severe questions in three fields: data conjoint, data switch and export, data application. This paper puts forward the establishment idea, confirms the technique route of the building, and analyses the key problems. Then the establishment solutions are given: firstly, the suitable vertical datum should be chosen based on the tidal character of local sea separately; secondly, the conversion model among the different vertical datum should be established; thirdly, the transition model in neighborhood should be set up. Then the marine vertical datum seamless system is built, which can reflect the interrelation among the different vertical datum and suit the whole sea.

1. Introduction

The datum of hydrography and cartography is the important part in the geodesy datum, and it is a special expanding of geodesy datum in sea and other waters [1, 2]. Although the datum of hydrography and cartography consists of horizontal datum and vertical datum, its particularities are mainly shown in its depth datum. The depth datum is different from vertical datum of terrestrial survey in substance because the sea level changes continuously. As a result, its own datum is needed.

The substance of depth datum is the original plane for depth survey and its correlative elements. The vertical datum of modern hydrography and cartography and other fields consists of reference ellipsoid plane, geoid, mean sea level, chart depth datum, etc. At present, the height datum of land is “1985 National Elevation Benchmarks” which is confirmed by the mean sea level at special site (Qing-Dao) in China. However, the marine depth datum adopts the theoretical lowest tide surface which should ensure safe navigation and keep sea-route utilization sufficiently [3–5]. Since the chart datum is often different among countries and regions, the same soundings may express different depth. Thus a good many problems of marine depth datum in different area are produced, such as disperse, changing acutely, discontinuity and disuniting from height datum of land, et al. All in all, there are three austere problems extruded in the era of global navigation developing progressively and coastal zone using increasingly: firstly, the surveying data in different area and time can not be conjoint, not to say the data conjoint between land and sea, so the use value and surveying efficiency are decreased; secondly, depth data from different datum cannot switch and export expediently, so it adds the difficulties for the increasing of expressing precision in marine spatial geography information; thirdly,
chart products use different datum in distinct regions bring inconvenience and potential danger for the usage of user and navigation safety. Consequently, it is urgent to deal with the different datum scientifically and confirm the relationships among them. Therefore, the paper combines with the acquired domestic and international research work, takes the realism and feasibility into account, studies the continuous marine vertical datum system at the “system” level, which is based on the present marine vertical datum.

2. The Establishment of Technical Route

2.1 The meaning of marine vertical datum seamless system

The marine vertical datum seamless system is advanced specially in this paper, which means a set of reference datum which does not change with time or zone and the transition among all datum.

The purpose of the seamless system foundation is ensuring the continuity and smooth of the datum which expresses the vertical information, confirming the geodetic meaning and precision index of all datum, then establishing the token relations among the depth datum, geodetic coordinate system, global and regional height datum and their frames concretely, reaching the coherence of vertical spatial information on geometrical and physical sense finally.

2.2 The academic anatomy on the foundation of seamless system

2.2.1 The existent essential questions for the foundation of seamless system

The chart datum generalized include height datum and depth datum, they all belong to the category of marine vertical datum. Marine vertical datum are the expanding of terrestrial vertical datum in sea and other waters, at the same time, they are the beginning surfaces for hydrography and other elements, and they are also the important bases for the cognizance and expression of sea. The academicians all over the world always search and establish suitable vertical datum system in order to cognize and express sea and other waters better. Now the marine vertical datum include earth ellipsoid surface, (quasi) geoid, mean sea level, chart depth datum and so on[6,7].

The height beginning surface for mountains, islands and reefs in chart is height datum. The height datum adopted in China is “1985 National Elevation Benchmarks”, and it is mean sea level in several years at Qing-Dao tidal station materially. But there are still some isolated islands so that we cannot utilize the datum. For example, Tai Wan and Zhou-shan archipelago take the local mean sea level as height datum, so there are some independent datum. Otherwise, the lighthouses, bridges, trolly wires and cables loaded in chart are calculated from mean high water springs.

Accordingly, the datum for soundings signed in chart is depth datum. In general, depth datum is consistent with tide height datum. That is to say, actual depth is charted depth plus actual water level at either time, and the uncover height of rock which covers and uncovers is also calculated from depth datum. Although the chart depth datum have different definitions and formulae in different countries, they all take navigation safety and employment rate of fairway as basic drawing principles, so they are all the depth datum which have tight contact with local tidal range and meet the application need. The chart depth datum adopted in China is the theoretical lowest tide surface, which meaning is the lowest tide surface that the sea level can reach in theory. It is calculated from 13 symphonious constants of partial tide and Frakimirsky formula according to the present Specifications for Hydrography[8]. The theoretical lowest tide surface calculated and confirmed from tidal parameter should be the continuous curve surface in theory. However, the location of tidal stations are discrete and the depth datum get from tidal data of each tidal station are different in fact, which led to the depth datum is in the discrete distribution that centered with each tidal station in local area. Accordingly, the depth datum does not change continuously but in a broken situation.

All in all, the height datum and depth datum in chart are not consolidated presently, and the depth datum per se is not continuous. It disadvantages navigation safety and sea exploitation seriously. The paper establishes the marine vertical datum seamless system to resolve the above problems.
2.2.2 The basal thought on the establishment of seamless system

The geodetic height of seabed can be measured based on the integration of high precision positioning technology and sounding technology. Hence the earth ellipsoid surface adopted by geodetic coordinate system is the most elementary seamless vertical datum on sea. It is also the elementary academic viewpoint about marine seamless vertical datum that most academicians held all over the world. If the marine vertical datum seamless system is established, the data get from different survey technologies and patterns can be expressed integrated, and the application-oriented conversion among the datum can be achieved. As far as the present research is concerned, the establishment of marine vertical datum seamless system can think 6 aspects over:

1) If the traditional bathymetry mode which controls water level at tidal station is adopted, we can get each average depth at minimum precision loss in sea (overcome the error composed of the depth datum ascertainment deviation and irrational correction of water level), so average sounding should be the basic data for sea depth.

2) The depth datum can be expressed as depth datum model relative to mean sea level (it is almost equal to theoretical maximum half tidal range model ), the average depth can be switched to charted depth based on the model, at the same time, it can be given corresponding precision (uncertainty) information.

3) The geodetic height of seabed got by the GNSS technology can be switched to the conservative sounding data in chart through the expressing model which is depth datum relative to earth ellipsoid surface (i.e. depth datum geodetic height model, it is the same as the height datum model expressed by quasi-geoid).

4) The average depth can convert to be expressed in national height datum system based on the sea surface topography model to realize the sea and land geography information expressed in uniform datum.

5) The vertical datum of chart and land topographic map can be united (i.e. sounding can be switched to the seafloor topography data in height system) based on the application of depth datum model (relative to mean sea level) plus ocean topography.

6) The height of light beacon, bridges over-sea, trolly wires which got by topographic survey can be switched to express in conservative height datum (mean high water springs), all should base on the mean high water springs model and sea surface topography model.

2.3 The establishment idea and approach of seamless system

2.3.1 The general establishment idea of seamless system

There are many existing marine vertical datum, and each datum has its own characteristic and adaptability. The aim of marine vertical datum establishment is to meet the need of survey and expression for different ocean tide character, analyze and utilize the characteristic of existing depth datum to establish the successional marine vertical datum and its maintainability frame according to the development actualities of survey technology nowadays.

The general establishment idea is put forward: firstly, the definition and design principle of seamless vertical datum should be studied in theory; secondly, erect the depth datum model which change gradually based on the exact tidal model; thirdly, choose the high resolution gridding model as the material realization of continuous seamless vertical datum; fourthly, the above seamless vertical datum are brought into geodetic vertical datum system through the continuous mean sea height model and land-sea geoid model which is expressed relative to earth ellipsoid; finally, the depth datum deviation model comes into being.

2.3.2 The material approach of seamless system establishment

The establishment of seamless system is substantively the engineering realization and quality control of depth datum and its deviation model. The establishment principle is considering the traditional definition habit and requirements enough, guaranteeing the continuity of depth datum and definition
consistency of each point theoretical lowest tide surface, erecting the relationship between the depth datum and geodetic vertical datum. All of these are in order to gather, analyze, manage, switch and apply the depth and height data easily in the modern surveying and mapping technologies. The following approaches can be adopted:

1) Choose the suitable seamless vertical datum according to each ocean tidal characteristic.
2) Establish the conversion model among the different vertical datum.
3) Set up the transition model in adjacent waters.

3. The key issues and resolvents

3.1 How to choose the suitable seamless vertical datum

We can choose the suitable seamless vertical datum according to each ocean tidal characteristic. At present, the seamless vertical datum which are suited for the Bohai Sea and Long River portal area have been found and tested feasibility\[9-13\]. Our marginal sea is expansive, each sea area has different tidal property and conditions, so the suitable seamless vertical datum have the corresponding distinctions too. Accordingly, we can use the existing domestic and international researches and ideas as references, confirm the suitable seamless vertical datum for each ocean according to its tidal property and condition. Then we can integrate with the following conversion and transition to establish the marine vertical datum seamless system.

3.2 The establishment of conversion model among different datum

We can use one seamless vertical datum as a bridge when the conversion model is established, then choose the vertical deviation model between the continuous or pre-continuous depth datum and ellipsoid surface. Therefore, we should describe the relation between the two vertical reference datum correctly. The used models are called vertical deviation model or separation model, which all have relative meaning. The vertical deviation model that depth datum relative to mean sea level is depth datum data model, it can be simply signed” L value” model. However, the geoid height model of depth datum described the deviation model between the depth datum and ellipsoid surface, so it is called depth datum separation model or deviation model for short in order to avoid meaning confusion. The material application of the following formulae composed the conversion model among vertical datum.

The conversion relation among the different vertical datum can be described in the below formulae, where $\bar{h}(\varphi, \lambda)$ is geodetic height of mean sea level, $N(\varphi, \lambda)$ is global unification geoid height, $\Delta N(\varphi, \lambda)$ is the vertical deviation that national height datum relative to global geoid, $\zeta(\varphi, \lambda)$ is local sea surface topography relative to national height datum, $L(\varphi, \lambda)$ and $MSH(\varphi, \lambda)$ are chart depth datum and mean high water springs relative to mean sea level respectively, $h_{CD}(\varphi, \lambda)$ and $h_{MSH}(\varphi, \lambda)$ are geodetic height for chart depth datum and mean high water springs, correspondingly, $H_{CD}(\varphi, \lambda)$ and $H_{MSH}(\varphi, \lambda)$ are (normal) orthometric height for above two datum.

$$\zeta(\varphi, \lambda) = \bar{h}(\varphi, \lambda) - N(\varphi, \lambda) - \Delta N(\varphi, \lambda) \quad (1)$$

$$h_{CD}(\varphi, \lambda) = \bar{h}(\varphi, \lambda) - L(\varphi, \lambda) \quad (2)$$

$$h_{MSH}(\varphi, \lambda) = \bar{h}(\varphi, \lambda) + MSH(\varphi, \lambda) \quad (3)$$

$$H_{CD}(\varphi, \lambda) = \bar{h}(\varphi, \lambda) - N(\varphi, \lambda) - \Delta N(\varphi, \lambda) - L(\varphi, \lambda) = \zeta(\varphi, \lambda) - L(\varphi, \lambda) \quad (4)$$

$$H_{MSH}(\varphi, \lambda) = \zeta(\varphi, \lambda) + MSH(\varphi, \lambda) \quad (5)$$

3.3 The establishment of transition models in neighborhood.

We can get the vertical datums suitable for different sea character after the first step, they are discrete and independent, but the ocean is a macrocosm. Although each sea has different tidal character for the
sake of sea shape, depth, seafloor topography and other natural conditions, they are not dissevered. Consequently, the author consider we can use the distance weighted method to analyse data, combine with the local tidal data to calculate the influences that two discrete datums put on the neighborhood, then the most perfect transition models can be got. Thus the many discrete seamless vertical datum can be united into a continuous marine vertical datum system.

For example, in Fig.1, Region A, B and C denote the Bohai Sea, the Huanghai Sea and Yangtze River Estuary respectively, Region A and C have adopted CGCS2000 ellipsoid surface and depth datum seamlessly as seamless vertical datum, according to the present research of author, CGCS2000 ellipsoid surface also can be adopted as the seamless vertical datum for the Huanghai Sea. The vertical datum in Region A and B are the same one, thus they can be conjoint directly, but the two areas have different tidal property which make the corresponding deviation models are dissimilar. Accordingly, we should use two models to extend calculation in neighborhood (i.e. shadow in Fig.1) and apply actual data to compare, then confirm the weight of each model in this area to get the perfect transition model. Though Region C lies in the East Sea, it is a special part. Then we should transfer the model in Region C at first, apply data of the East Sea to calculate and test its transfer precision whether meet the requirement. If it can meet, we can establish the transition model between the Huanghai Sea and the East Sea. With the vertical datums of Region B and C being different, we can choose a datum which have relations with the two datums as bridge firstly, then use the anterior thought to calculate and confirm model.

4. Conclusions
The marine vertical datum system and its establishment method are very important for the conjoint and share of marine-land data, marine fully exploitation and utilization, the safety and high efficiency of navigation and so on. The existent research fruits only suit one part region, without the seamless vertical datum for the whole sea. Accordingly, the paper puts forward the establishment of marine seamless vertical datum system, and investigates the material establishment method. At first, the paper chooses suitable vertical datum according to each sea tide characteristic, then it establishes the conversion model of different datum and develops the transition models in neighborhood, thus the vertical seamless datum system which can suit the whole sea is established. The paper is expected to resolve the problems produced by the disunion of vertical datum, and avoid the potential danger in navigation.
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