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Methods Development for Assessing Sea Depth on the Northern Sea Route Depending on the Recording of Hydrographical Relief Details

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ABSTRACT

In this article we presented the assessment of hydrographic study of routes of the Northern Sea Route (NSR) for safety of commercial shipping. Arctic Sea is mainly shallow, that is well known and demonstrated by the depth distribution and seas Square.
The main characteristics of high-altitude and traditional coastal routes are provided. In article data on distribution of depths on the water area of the Arctic seas are generalized. It should be noted that the difference between the minimum and the through depth increases with decreasing the details of mapping. It is noted that navigation on SMP is realized along the recommended routes that is connected with insufficient hydrographic study of a relief of a bottom. Severe ice conditions force vessels to deviate the recommended ways, both at independent swimming, and under conducting of the ice breaker because of risk of receiving ice damages. The extreme draft of the vessel calculated on the minimum depth found on the route at discrete measurements doesn't guarantee safe swimming on the route. At increase in discretization the level of credibility to the calculated value of extreme draft of the vessel decreases because the probability of presence of depth, which is smaller, than minimum depth found on the route, increases.
The original technique of an assessment of depths through passage of routes NSR is offered and examples of calculations are given. All studies and researches were carried out on the Arctic Faculty of Admiral Makarov state university

KEY WORDS: Northern Sea Route; Hydrographic study; Passing depth; Vessel draft; Minimum depth; Detail mapping.

INTRODUCTION

Northern Sea Route (NSR) passes through the Kara Sea, the Laptev Sea, the East Siberian sea and the Chukchi sea, and also northeast part of the Barents sea and northern part of the Bering sea. The length of the NSR tracks fluctuates from 2700 miles for circumpolar (high-latitude) routes to 3500 miles for the coastal routes. Total length of the NSR tracks exceeds 14 thousand miles. The access to the NSR tracks from the West is carried out through the Kara Gate strait or from the North from the Zhelanie cape. The distance from the port of Murmansk to the Kara Gate strait makes 528 nautical miles. The distance from the port of Murmansk to the Zhelanie cape is 758 nautical miles. The entrance on the NSR tracks from the East is carried out through the Dezhnyov strait. The distance from the Dezhnev Cape to the port of Petropavlovsk-Kamchatsky makes 1037 nautical miles.

Gavrilov (2015) described in detail the legal status of NSR and it is provided by the international marine legislation.

The Arctic seas are mainly shallow that is shown by distribution of depths and on the area of the seas in table 1 according to (Reshetnyak, 2006). In the Laptev Sea and the East Siberian Sea the depths to 20 meters occupy a half and more of the water area. In the Kara Sea this share reaches only 9%. The main traditional coastal and high-latitude NSR tracks pass on these shallow sites.

Table 1. Distribution of depths on the area of the Arctic seas

Range of depths, m	Share of area, %		
	The Kara Sea	The Laptev Sea	The East Siberian sea
0-10	3,5	11,1	14
10-20	5,3	37,4	47
20-30	10,1	22,7	25,5
30-40	9,3	17,8	13,1
40-50	3,8	11,0	-
50-100	18,3	-	-
100-200	146	-	-
> 200	214	-	-

The charts manufactured on materials of the hydrographic researches till 1990 make the basis of the collection of navigation sea charts. The detail of the performed mapping of bottom relief is shown in table 2 according to (Reshetnyak, 2006).

The charts made on materials of the hydrographic works performed by Federal State Unitary Enterprise "Hydrographic Enterprise" (Russia, official website – http://www.hydro-state.ru/) since 2010 till present are also included Into a collection. These charts cover parts of areas of the designed transit high-latitude routes and the water area of the Ob Bay and the Yenisei strait with passes (Federal State Unitary Enterprise "Hydrographic Enterprise", 2016)

Table 2. The detail of the mapping of bottom relief on the area of the Arctic seas

The detail (m)	Share of area, %			
	The Kara Sea	The Laptev Sea	The East Siberian sea	The Chukchi Sea
≤500	28	35	15	9
1000	38	39	20	-
2000-4000	16	11	14	21
≥4000	10	10	10	-
route	8	5	41	70

DEFINITION OF RESEARCH PROBLEM

NSR is mainly passing on sites of the Arctic seas with numerous underwater dangers through Severnaya Zemlya Archipelago and New Siberian Islands Archipelago on the Dmitry Laptev strait, Vilkitsky strait and Shokalsky strait. Navigation on the water area of NSR is carried out on the recommended ways. Significant long-term experience at the passage of these routes has not been accumulated yet; it belongs to the period of free navigation in clear water and at icebreaking assistance. The first options of the routes were mapped based on successfully completed navigations (Dmitriev, 2015; Pastusiak, 2016). The main criterion by which the routes for winter season were chosen was degree of landfast ice and adjacent areas, free from ice. During the summer season the routes were mapped so that to avoid the areas where there are ice massifs. Recently special attention is paid to the passing depths (Afonin, 2016; Batalin, 2008) because the commercial fleet has considerable draft.

Representation of an underwater relief of the water area of the Northern Sea Route (NSR) is based on discrete (in planned position) determination of depths and their coordinates. Such way of hydrographic mapping doesn't guarantee detection of all local raisings of a bottom which can be navigation dangers.

The extreme draft of the vessel calculated on the minimum depth found on the route at discrete measurements doesn't guarantee safe navigation on the route. At increasing of discretization (sampling) the level of credibility to the calculated value of extreme draft of the vessel decreases as the probability of depth presence smaller than minimum, found on the route, increases.

Study of these routes corresponded to requirements of the standards existing at the time of mapping and provided navigation of vessels with draft up to 6-7 meters in conditions of summer - autumn navigation. In winter navigation at icebreaking assistance the safety of transport vessels was provided by ice breaker which were going ahead and having the draft of 8 or 12 meters (Admiral Makarov State University of Maritime and Inland Shipping (SUMIS), 2016; Federal state Institution “The Northern Sea Route Administration”, 2017).

Hydrographic study of the water area of NSR by modern criteria of the International hydrographic organization (IHO, S-44/5 (Standard of International Hydrographic Organization S-44/5, 2008)) is insufficient

According to these criteria it is necessary to perform the hydrographic areal mapping on the NSR, providing the identification of navigational hazards, which sizes are 1x1 and 2x2 meters, depending on the water reserve under the vessel keel (Admiral Makarov State University of Maritime and Inland Shipping (SUMIS), 2015).

Currently, transit high-latitude NSR tracks within a 2 kilometer strip (Federal State Unitary Enterprise "Hydrographic Enterprise", 2016; Federal state Institution “The Northern Sea Route Administration”, 2017) and approaches to the ports of Dudinka and Sabetta correspond to such conditions.

The shallow-draft vessels pass on the coastal NSR tracks. Operation on coastal routes of courts with big draft without additional hydrographic inspection it is accompanied by risks of navigation incidents. Navigation on the recommended ways is applied in areas with insufficient hydrographic study according to rules of NSR Administration (Federal state Institution “The Northern Sea Route Administration”, 2017).

Shallow water in a combination to difficult ice conditions of the Arctic are the major complicating factors of year-round navigation of heavy-tonnage vessels on the NSR.

Severe ice conditions force vessels to deviate the recommended ways, both at independent navigation, and at pilotage using icebreaking because of risk of ice damages receiving.

Considerable removal from the recommended ways in the conditions of shallow water increases risk of the accidents connected with grounding or contact of ground in the conditions of insufficient hydrographic study of adjacent water areas.

High variability in ice conditions means that vessels often cross a part of NSR along a route where ice conditions make impossible the further navigation, then there is a choice of other option at dynamically changing ice situation. All options available in the concrete seas are carefully discussed. Special attention is paid to the straits dividing certain seas on NSR.

DEVELOPMENT OF TECHNIQUE FOR ASSESSMENT OF THE PASSING DEPTHS ON NSR

The extreme draft of the vessel calculated on the minimum depth found on the route at discrete measurements doesn't guarantee safe navigation on the route. At increase in discretization the level of credibility to the calculated value of extreme draft of the vessel decreases as the probability of depth presence, smaller, than minimum depth found on the route, increases.

Assessment of the extreme draft of the vessel *d(L)* guaranteeing safety of navigation on routes in shallow water in the conditions of insufficient hydrographic study ($L \neq 0$) is determined by a formula:

$$d(L) = f\left[Z_{\min}(p), \Delta, \Delta_L(p; L)\right], \quad (1)$$

where L - discretization of depths measurements; $Z_{min}(p)$ - the minimum depth determined with probability p; Δ - received reserve of water under the keel; $\Delta_L(p;L)$ – the amendment for uncertainty of value of the minimum depth.

The following ratios are valid for areal mapping:

$$\Delta_L(p = 1; L \to 0) = 0 \quad (2)$$

$$d(L \to 0) = f\left[Z_{\min}(p = 1), \Delta\right] \quad (3)$$

The amendment for uncertainty $\Delta_L(p;L)$ considers morphological and morphometric features of an underwater relief, his type and range of depths of the water area.

Formulas (1) – (3) are used for calculation of the extreme draft of the vessels on NSR.

The software (Afonin, 2016.) was developed for calculation of the extreme draft of the vessel. It is intended for the following types of hydrographic mapping of underwater relief: areal mapping, mapping with parallel tacks, ice measurement, route measurement.

Type of the realizing electronic computer is IBM PC compatible personal computer. Programming language is ObjectPascal (development environment is Lazarus, Delphi). The type and version of operating system is Windows 2003/XP/7, Linux(Ubuntu).

At calculating the program produces results of determination of passing depths corresponding to the extreme draft of the vessel in 6.0 meters, at the same time key parameters of the initial massif of depths and area of passing depths are displayed.

The given technique was used for assessment of passing depths (Batalin, 2008; Federal State Unitary Enterprise "Hydrographic Enterprise", 2016) on NSR. The table 3 shows the characteristics of high-latitude routes of NSR surveyed in 2010-2015 by detailed mapping. The detailed mapping provides sufficient hydrographic study of the water area of high-latitude routes. The first column shows direct and back courses of straight sections of the recommended way. The second column shows minimum depths found on the allocated straight sections of the recommended way.

The detailed mapping has allowed to find the minimum depths and all available underwater obstacles dangerous to navigation.

The values of passing depths are given in the third column. Passing depths differ from the minimum depths at a size of free reserve of water equal 2.0 meters.

Table 3. Characteristics of high-latitude routes

Course: direct - back	Minimum depth, m	Passing depth, m	Detail of mapping
West part			
36.2-216.2	44	42	areal mapping
74.5-254.5	25	23	areal mapping
90-270	45	43	areal mapping
56.4-236.4	27	25	areal mapping
65.6-245.6	35	33	areal mapping
Middle part			
53.1-233.1	24	22	areal mapping
90-270	19	17	areal mapping

61.3-241.3	21	19	areal mapping
94-274	23	21	areal mapping
53.1-233.1	24	22	areal mapping
East part			
106.2-286.2	22	20	areal mapping
132.5-312.5	22	20	areal mapping
137.7-317.7	20	18	areal mapping
119-299	28	26	areal mapping

The characteristic fragment of the coastal route of NSR and his key parameters are given in tab. 4.

Table 4. Characteristics of fragment of the coastal route

Exit from the Vilkitsky strait and Shokalski strait				
Course: direct - back	Length, km	Depths: min/max, m	Passing depth, m	Line spacing, *L*), m.
112.4-292.4	102	25/66	15.0	500
126.4-306.4	194	18/60	6.0	1000
0-180	104	20/185	2.0	2000

It should be noted that the divergence between the minimum and passing depths increases at reduction of detail of mapping (increase of parameter *L*).

DISCUSSION OF RESULTS

The developed technique and the software together with other forecasting models (Aksenov, 2017; Yamaguchi, 2016) and laying of safe routes in the water area of NSR will allow to provide navigation in the Arctic seas and reduce the economic risk connected with search of optimum routes and unpredictable change of time of voyage.

All data obtained in work are in good agreement with researches of other authors (Lee, 2015; Zhao, H., Hu, H., & Lin, Y., 2016; Zhao, H., & Hu, H., 2016) describing trial passes of the commercial fleet in the water areas of NSR by the Chinese and Korean companies in 2013-2014.

CONCLUSIONS

1. Techniques for assessment of passing depths on NSR tracks which consider both hydrographic study of routes, and morphological and morphometric features of underwater relief were developed.

2. Calculated data allow to estimate the possible minimum draft of vessel for the safety of navigation and identification of more optimum routes that is urgent in case of development of new tracks of NSR.

3. The developed technique and the software together with other forecasting models of safe conditions of navigation allow to find more optimum routes for high-latitude tracks of NSR

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