Determination of the width of Haihua Island branch channel based on simulation test

Yisen Xu¹, Fengwu Wang¹, Zhongxun Yin¹ and Sihang Liu¹
¹ School of Navigation, Dalian Maritime University, Dalian, Liaoning, 116000, China
*Corresponding author’s e-mail: 2508717301@qq.com

Abstract. In order to ensure the safe navigation of ships, it is necessary to provide ships with sufficient fairway width for navigation. We selected a suitable ship model, extracted the ship test track zone through simulation test, selected the track point along the edge of the track zone, and integrated it. According to the distribution of edge track points, the channel should be appropriately widened so that most of the track points are within the new channel. The width of the channel widened by the edge track point has a good consistency with the calculation results of the "General Design Specification for Seaports", indicating that it is feasible to determine the channel width using this method.

1. Haihua Island Fairway Status
Danzhou City, Hainan Province is located in the Beibu Gulf, with beautiful scenery, unique tropical scenery and cultural landscapes. The State Council approved the idea of building a Hainan International Tourism Island and supporting the construction of a free trade island. An international cruise port is planned to be built in the sea area of Haihua Island in Yangpu Port.

According to the current channel of Haihua Island and the plan of Haihua Island channel, it is planned to build the channel as shown in Figure 1. Among them, the main channel is the original channel, and the cruise branch channel and port area are all planning areas.

Figure 1. the plan figure of Haihua Island cruise port
The azimuth angle of the branch channel is 116°00′00″~296°00′00″, about 3000m long and 215m effective width. It is predicted that 200,000 GT and above cruise ships will visit in the future. Therefore, simulation tests are required to verify whether the planned channel width is sufficient for ships to sail.

2. Preparation of test

The simulation test platform uses a large ship maneuvering simulator developed by the Maritime Technology Research Institute of Dalian Maritime University. In order to verify the accuracy of the simulation test, the error of the test ship model was compared before this test. The result was compared with the simulation test of typical ship model data and literature [1,2,3]. The error is within the acceptable range (10 %). According to the analysis of the design ship model and the engineering feasibility report, the 225,000 GT cruise ships Allure of the seas and Oasis of the seas were used as prototypes, and the simulated 225,000 GT cruise ships were designed and tested. The ship parameters are shown in Table 1. The ship is designed as a two-engine boat, with good operation and reliable mooring without tugboat assistance.

Table 1. The parameters of simulated ship model

| Type                      | Length (m) | Beam (m) | Draft (m) | Displacement (t) | Speed (kn) | Bow thruster (kW) |
|---------------------------|------------|----------|-----------|------------------|------------|-------------------|
| 225,000GT cruise (Oasis)  | 362        | 47.7     | 9.3       | 105,700          | 22         | 4×5500            |

According to the simulation test of the current field of Haihua Island and the statistical results of the wind current data, the water velocity near the entrance is 0.1~0.3m/s, and the velocity in the harbor is 0.02~0.1m/s, but the channel is larger, 0.75m/s. The upward water flow is towards NE and the downward flow is towards SW, which is close to the cross-flow direction. From October to April each year, the prevail wind direction is NE, and the SW-SSW wind prevails from June to August, especially in July and August. The probability that the wind is less than 7 is 99.91%. Therefore, the design test plan is shown in Tables 2 and 3. In order to ensure the accuracy of the test and improve the accuracy of the test, every test should be carried out 3 times in each group at least. All of the tests used Ship type Oasis (full state), and the current velocity depended on current field which was determined by simulation test of the flow field of Haihua Island and the statistical results of the wind current data.

Table 2. Port entry

| No. | current direction | Wind direction | Notes                          |
|-----|-------------------|----------------|--------------------------------|
| 1.  | Flood tide (NE)   | SW-7           | Wind and current on same side  |
| 2.  | Ebb tide (SW)     | SW-7           |                                |
| 3.  | Flood tide (NE)   | SSE-7          | Wind and current on same side  |
| 4.  | Ebb tide (SW)     | SSE-7          |                                |
| 5.  | Flood tide (NE)   | S-7            |                                |
| 6.  | Ebb tide (SW)     | S-7            |                                |
| 7.  | Flood tide (NE)   | NE-7           | Wind and current on same side  |
| 8.  | Ebb tide (SW)     | NE-7           |                                |
Table 3. Departure from port

| No. | current direction | Wind direction | Notes                                      |
|-----|-------------------|----------------|--------------------------------------------|
| 9   | Flood tide (NE)   | N-7            |                                            |
| 10  | Ebb tide (SW)    | N-7            |                                            |
| 11  | Flood tide (NE)  | SW-7           | Wind and current on same side              |
| 12  | Ebb tide (SW)    | SW-7           |                                            |
| 13  | Flood tide (NE)  | SSE-7          | Wind and current on same side              |
| 14  | Ebb tide (SW)    | SSE-7          |                                            |
| 15  | Flood tide (NE)  | NE-7           | Wind and current on same side              |
| 16  | Ebb tide (SW)    | NE-7           |                                            |

3. Simulation test

This test team was composed of many experienced teachers and captains. Because the comprehension and test habits of the testers are different, which are reflected in the test results. The V-dragon 3000 simulator developed by Dalian Maritime University was used in this experiment.

Figure 2. Entry test with SW wind (B.F. 7) and NE current

Figure 2 shows the trajectory of sailing and berthing under the influence of level 7 SW winds and NE currents. It can be seen that the ship has been better controlled, the course change is basically in a stable state, and there is no departure from the channel or stranding during navigation, and finally successfully moored.

Figure 3. Entry test with SW wind (B.F. 7) and SW current
Figure 2 shows the navigation trajectory of sailing and berthing under the influence of 7-level SW wind and SW flow. It can be found that due to improper maneuvering and high wind force, the ship failed to complete the berthing under the condition of steering only.

Figure 4 shows the trajectory of sailing and departing under the influence of level 7 SW wind and SW flow. It can be seen that the ship's course is very stable under the normal operation of the side thruster. Finally the test was successfully finished.

4. Analysis of test

Figure 5. Entry test with SSE wind( B.F. 7) and NE current (1)

Figure 6. Entry test with SSE wind( B.F. 7) and NE current (2)
4.1. The results of test

The wind and current in this sea area are relatively large, and it is necessary to change the course to ensure a leeway and drift angle to make the ship navigate safely. The test ship is a large ship (length 362m, width 47m, draft 9.3m, GT225, 000), causing that the ship needs a large space for changing course and speed, although this ship has good maneuverability. The channel in the figure is only 215m, and the width of the ship is 47m. As shown in Figures 5 and 6, when the ship changes the course, it has been close to the side line of channel, even part being outside the channel. It is clear that the 215m width of channel is not enough for the ship.

From the test trajectory, it can be seen that maintaining course in the cruise area (including the branch channel entrance, 215m wide channel, and southeast entrance) is the most difficult. This is because the test wind direction is mostly NE and SW winds, which is just right to ship beam. The flood current is NE current, and the ebb current is SW current, which happens to be a beam current. When sailing close to the entrance of port, the current rate will change, which increases the difficulty of maneuvering. It is often more difficult to control when the wind and current are on the same side.

4.2. Calculated channel width

After consulting the literature [4,5,6,7,8,9,10,11], and comparing the calculation methods of the channel widths of various countries, the "General Specification for Seaport Design" (JTS165-2013) was selected as the reference for calculating the channel width. According to the "General Design Specification for Seaport" (JTS165-2013), the width W of the one-way channel is calculated from the formula $W = A + 2c$, where $A$ represents the width of the trajectory and $c$ is the affluent width (between the ship and the bottom edge of the channel). And $A=n(L\sin\gamma+B)$, where $n$ is the ship drift rate, $L$ is the design ship length, $B$ is the design ship width, and $\gamma$ is the leeway and drift angle.

| Wind force | Beam wind≤B.F.7 |
|------------|-----------------|
| Beam current $V$ (m/s) | $V \leq 0.10$ | $0.10 < V \leq 0.25$ | $0.25 < V \leq 0.50$ | $0.50 < V \leq 0.75$ | $0.75 < V \leq 1.00$ |
| $n$ | 1.81 | 1.75 | 1.69 | 1.59 | 1.45 |
| $\gamma$ (°) | 3 | 5 | 7 | 10 | 15 |

| Ship type | General cargo | Bulk carrier | Oil tanker/Chemistry carrier |
|-----------|---------------|--------------|-----------------------------|
| Speed (kn) | ≤6 | >6 | ≤6 | >6 | ≤6 | >6 |
| $C$ (m) | 0.5B | 0.75B | 0.75B | B | B | 1.5B |

The design code does not mention the value of the cruise ship's affluent width. Here, the value is taken from the general cargo ship or container ship standard, calculated according to the test ship data, and the results are as follows (Table 6).

| Speed (kn) | L (m) | B (m) | $\gamma$ (°) | Drift rate | A (m) | $c$ (m) | W (m) |
|-----------|-------|-------|--------------|------------|-------|--------|-------|
| ≤6 | 362 | 47 | 7 | 1.69 | 153.987227 | 23.5 | 200.9872 |
| 362 | 47 | 10 | 1.59 | 174.678418 | 23.5 | 221.6784 |
| 362 | 47 | 14 | 1.45 | 195.134803 | 23.5 | 242.1348 |
The test channel is 215m and can meet the conditions of cross wind \( \leq 7 \), cross flow \( 0.25 < V \leq 0.5 \text{m/s} \), and speed \( \leq 6 \text{kn} \). However, according to the requirements of the test plan, where the current velocity of the channel is 0.75m/s, the leeway and drift angle should be at least 10°. In this case, the width of the 215m channel is slightly insufficient.

4.3. The distribution of edge points of ship trajectory

During the actual voyage, according to the test data, the speed in the branch channel will be greater than 6kn, and the leeway and drift angle is greater than 7°. Therefore, when navigating in the channel, there are several sets of test trajectories close to the edge of the channel, or even overlap. And part of the trajectories slightly deviate from the channel.

Considering the width of the test trajectory and the space occupied by the ship [12], extract each set of test trajectories and study the actual distribution of them. If all the measured trajectories are integrated and displayed, some trajectories may cover other trajectories, which may not display the distribution of all trajectories in the channel. So the outermost track points of the trajectory are taken. The edge track point, which can reflect the relationship between the width of the trajectory and the channel. As shown in Figure 7, Figure 8 and Figure 9, the green and red points are the edge track points.

![Figure 7. The edge track points](image)

After removing the part of the test that has a large operation error and the track deviation is too large, the remaining test track points will be processed uniformly and redrawn in the channel. We extracted those point from every trajectory. First, extract the navigational coordinates of the simulated ship in each track and find the coordinates of the edge track points of the section. Second, calculate the distance between each edge track point and the channel boundary, and convert it into coordinates that can be read by the V-dragon3000 simulator. Finally, draw a point figure of the ship's edge.
From the track points in Figures 8 and 9, the outermost track points are mainly concentrated at the entrances and entrances of the branch channel, but relatively few in the channel. The reason may be that the course is relatively stable when navigating in the channel, and generally no large changes are required in the course, and when navigating at the entrance and entrance of the branch channel, the course needs to be changed to adapt to the direction of the fairway. Due to the fact that there is a decrease in the current at the entrance, this will make the ship's steering less consistent with the expected effect, which also causes the officer to control the ship insufficiently, causing the ship to deviate from channel.

During the berthing and entering the channel, the test ship turned from the south side of the main channel in the upper left corner of the figure to the right. It can be found that the track points at the entrance of the branch channel are concentrated on the south side of the channel, which may be due to navigating with wind and current on same side. When the ship receives wind and current from the same side like the current direction is SW, the ship turns to the right. At this time, the ship will have a tendency to drift to the southwest side, and the crosswind and crosscurrent, and the wind speed and current rate will at a higher value. The drift will make it difficult for the ship to maneuver, causing it to drift out of the channel on the south side when turning. In the process of entering the entrance, the current will decrease and you need to turn to the right. At this time, the ship will reverse, making the ship's track point on the north side of the door more than the south side. When leaving the port, the speed is faster than when docking, so the ship's rudder efficiency is better, and it is less affected by the ship's reverse when turning, so the track points are more evenly distributed at the entrance of the channel. When sailing away from the port, the current rate will suddenly increase. At this time, the speed of the ship is still low and the rudder efficiency is poor. Therefore, it can be seen that there are more track points near the entrance than inner the entrance, and due to reverse movement, ship will move to the right, the track points are concentrated on the north side of the channel.
4.4. Recommended channel width
From the distribution of track points in Figure 9 and Figure 10 above, we can know the overall condition of the outermost edge of the test track zone, because these track points are the test cases where the error and large deviation of the track zone have been eliminated. Therefore, these distributions can be roughly reflected in the actual operation situation of most ships when sailing in the channel. It can be seen that in the area on the north side of the entrance, the channel should be appropriately widened to leave a affluent width for the ship to adjust the course. According to the actual conditions of drift and leeway angle, it is recommended that the channel width here should be at least 245m wide under the conditions of beam wind ≤7, beam flow 0.5 < V ≤0.75m/s, and speed> 6kn.

According to the distribution of track points, channel on the north side of the entrance should be widened by 20-40m, and the south side of the channel should be widened by 0-20m. At the same time, at the turn of the channel entrance, appropriate widening should be carried out to prevent the ship from deviating from the channel during the turn. This is basically consistent with the channel width calculated earlier.

5. Conclusions
(1) Due to the large wind-receiving area of the cruise ship and the large side angle during the test, it is also affected by the beam current, resulting in a deflected leeway and drift angle greater than 7°;
(2) The predicted widening channel width obtained from the trajectory zone obtained through the simulation test is basically consistent with the calculated channel width;
(3) Due to the combined influence of the ship's turning direction, reverse movement, and changes in current velocity, the track points are concentrated on the north side of the entrance and the south side of the channel entrance when docking, and on the north side of the port entrance when departing;
(4) The 215m wide channel at the entrance of Haihua Island Port Area needs to be widened. It is recommended to widen 20-40m to the north, 0-20m to the south, and at least 245m to suit the navigation requirements.

References
[1] Gang C.(2016) Bulk Terminal Navigation Simulation and Analysis Based on Maneuvering Simulator. D. Dalian Maritime University, Dalian.
[2] Xiaoke G.(2014) Research on BBM Assessment Modal Based on the VDragon3000Maritime Simulator. D. Dalian Maritime University, Dalian.
[3] Xin X.(2015) Research on Vessel Traffic Simulation System Based on Maritime Simulator. D. Dalian Maritime University, Dalian.
[4] Fenglei X(2015) A Study on Two-Way Navigable Channel Width of Weihai Port's Major Channel. D. Dalian Maritime University, Dalian.
[5] Ye L.(2010) The Study of Fairway Width under Strong Wind and Current. D. Dalian Maritime University, Dalian.
[6] Xiliang N.(2010) The Comparative Study on the Design Standards between China's and Japan's Channel Width. D. Dalian Maritime University, Dalian.
[7] Ministry of Land, Infrastructure, Transport and Tourism (MLIT)(2009). Technical Standards and Commentaries for Port and Harbor Facilities in Japan. Japan: OCDI.
[8] British Standards Institution (2013). BS 6349: Maritime Works -Part 1-1: General – Code of Practice for Planning and Design for Operations. London: BSI.
[9] PIANC (International Navigation Association) (2014). Harbor Approach Channels-Design Guidelines.S. Brussels: PIANC.
[10] USACE (US Army Corps of Engineers) (2006). Coastal Engineering Manual. EM 1110-2-1100.
[11] ROM 3.1-99 (2007). Recommendations for the Design of the Maritime Configuration of Ports, Approach Channels and Harbor Basins. English version. Madrid: Puertos del Estado.
[12] Cui Z, Jinli X, Junmin M.(2015) Determination and analysis of ship track zone scale based on AIS information. J. Journal of Wuhan University of Technology(Transportation Science &
Engineering).39(06):1278-1282.