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CHANNEL WIDENING BY PROPELLER FLOW

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FOREWORD

In this report no 121, the Winter Navigation Research Board presents the results of research project ChannelWidening, Full scale trials of channel widening with IB Polaris. The capability of icebreaker Polaris to widen the broken ice channel using propeller flow was systemically investigated. Polaris was found to be able to break a 32-meter wide channel using propeller flow to widen the channel.

The Winter Navigation Research Board warmly thanks Riikka Matala for this report.

Helsinki

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FULL SCALE TRIALS OF CHANNEL WIDENING WITH IB POLARIS

FOR

FINNISH TRANSPORT AND COMMUNICATIONS AGENCY

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Summary:

The icebreaker Polaris capability of breaking a wide channel was investigated on full-scale ice trials in March 2021. The objective of the trials was to systemically study channel widening by propeller flow in full-scale with icebreaker Polaris.

The width of the channel behind the icebreaker was investigated at different icebreaker advancing speeds and different stern thruster toe-in angles. The channel width was determined by analyzing bird-view drone videos.

The test outcomes indicate that Polaris can efficiently create channel with width of 32 m by applying toe-in angles of 30 – 45 degrees when going ahead with a relatively high speed of 5 knots. The toe-in angles could also be used to widen a previously opened own channel. According to the test outcomes, the speed as high as 8 knots could be maintained while widening a previously broken channel, which is valuable for an assisting icebreaker.

Keywords:
Polaris, toe-in, wide channel

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TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The ice trials of IB Polaris were performed in the Bay of Bothnia on 12. -13.3.2021. The objective of the ice trials was to investigate Polaris capability to break a wide channel in documented conditions. The stern thruster toe-in angle and vessel speed influence on the created channel width was investigated in level ice conditions and in an old channel.

The channel width was determined based on video, which was recorded from above using a drone (*Figure 1-1*). Additionally, the channel width measurement was verified by manual measurement from a few locations.

The ice thickness varied between 47 - 59 cm in tests, which were performed in level ice. The ice was covered by homogenous, firm snow with thickness of about 25 – 37 cm. The ice flexural strength was relatively high.

Figure 1-1: The drone video snapshot used for measuring the channel width.

2 THE VESSEL

Polaris is a 24 m wide icebreaker, which is equipped with three ABB Azipod units: one 6.0 MW unit at the bow and two 6.5 MW units at the stern (in total 19.0 MW). The vessel was delivered in 2016. *Table 2-1* lists the main particulars of the vessel and a picture of the vessel is presented in *Figure 2-1*.

Table 2-1: Main particulars and propulsion parameters of IB Polaris.

L_{WL} [m]	97.37
B [m]	24.00
T_{design} [m]	8.0
P_{TOT} [MW]	6.0 + 2 × 6.5 = 19
Displacement [ton]	10.961
$D_{P\ bow}$ / $D_{P\ stern}$ [m]	4.0 / 4.2
Bollard pull [ton]	214

Figure 2-1: The icebreaker Polaris at the Bay of Bothnia, photo taken on 13.3.2021.

3 TEST PROCEDURES

3.1 GENERAL

The tests were conducted by using full power in stern azimuth units and adjusting the advance speed by controlling the power in the bow unit. In some tests, bow unit was used to slow down the vessel by rotating the propeller to the opposite direction or by turning the whole unit around to brake. The highest speed with each toe-in angle was achieved by using full power in each unit.

3.2 TEST PROGRAM

The primary objective of the trials was to evaluate the effect of stern thruster toe-in angles and vessel speeds on created channel width. The full test matrix is presented in *Table 3-1*.

Table 3-1: Test program.

Date	Test no.	Ice condition	Toe-in angle [deg]	Speed [kn]	Note
12.3.2021	1	Level ice	45	2.5	Bow unit turned around to reduce speed
	2	Level ice	45	4.0	
	3	Level ice	45	5.1	
	4	Level ice	30	7.5	
	5	Level ice	30	5.9	
	6	Level ice	30	2.4	Bow unit turned around to reduce speed
	7	Level ice	0	8.1	
	8	Level ice	0	12.1	
	9	Level ice	15	10.3	
	10	Level ice	15	8.2	
	11	Level ice	15	7.3	Bow unit propeller rotating to the opposite direction to reduce speed
	12	Level ice	15	4.1	Bow unit turned around to reduce speed
13.3.2021	17	Own channel	45	6.7	Channel widening in an easy old channel
	18	Own channel	45	8.3	Channel widening in an easy old channel
	19	Own channel	60	6.4	Channel widening in an easy old channel
	20	Own channel	60	5.1	Channel widening in an easy old channel

3.3 TEST AREA

The test area was in the Bay of Bothnia between Kemi and Oulu (*Figure 3-1*).

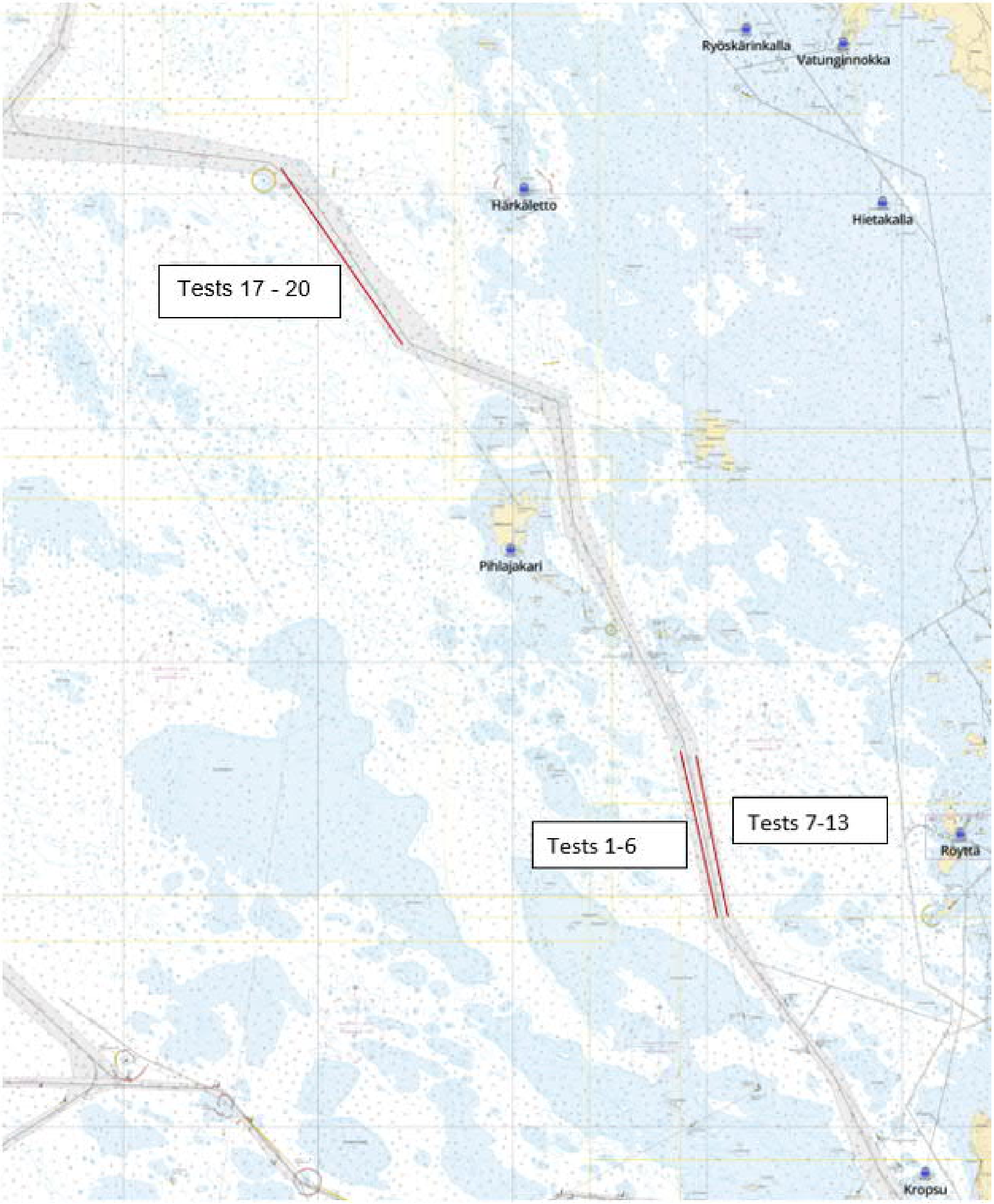

Figure 3-1: The test area in the Bay of Bothnia.

3.4 ICE PROPERTY MEASUREMENTS

Ice property measurements included ice thickness, snow cover thickness, ice density and flexural strength, which are presented in Appendix A.

3.5 CHANNEL WIDTH MEASUREMENTS

The channel width measurement is based on videos recorded from above by a drone on a fixed height. The vessel stern was visible in the video. Consequently, the vessel beam of 24 m is a reference width for the channel width evaluation as shown in *Figure 3-2*. The advantage of using the drone was the possibility to collect information continuously.

The channel widths on some specific locations were manually measured on site by a laser-based rangefinder, which are used to verify the estimated channel width from videos. *Figure 3-3* shows that the manual measured channel width (40 m) on site correlates well with the estimation from the drone video picture, indicating the channel width measurement based on videos is valid.

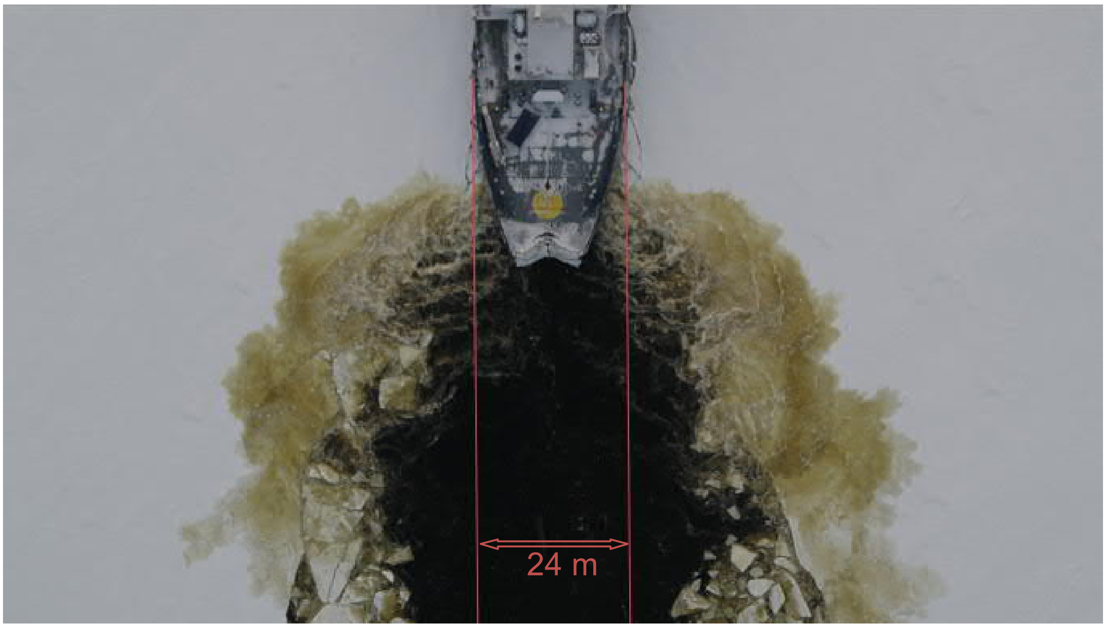

Figure 3-2: The analysis is based on comparing the created channel width to the vessel's beam (24 m).

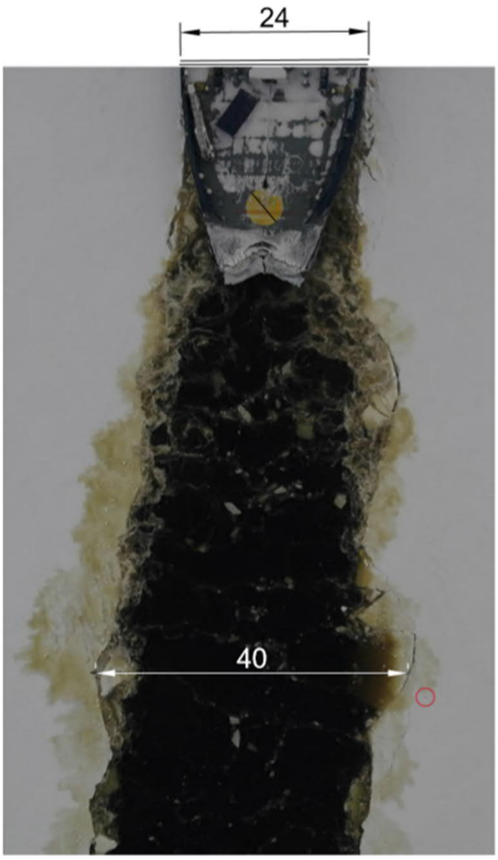

Figure 3-3: The manual measured channel width at the specific location (red circle) in Test 4 was 40 m, which correlates well with the estimated channel width based on the drone video snapshot.

3.6 CHANNEL WIDTH ANALYSIS

The channel width was measured on the video frames obtained from drone videos. A series of such frame pictures for each test video was obtained with the vessel's advancing distance of 10~20 m (interval) in full scale. In the analysis, a representative set of frame pictures were considered. The channel width was first estimated separately in each frame picture. For instance, *Figure 3-4 - Figure 3-6* shows the estimated channel width on one frame picture. The mean value of the estimated channel widths of all frame pictures for one test represents the channel width of the test in the final analysis in *Figure 3-7*. The following section outlines the analysis steps and provides necessary background information for interpreting the results.

During the testing, it was observed that the channel reached the maximum width surprisingly far behind the vessel. This was considered in the analysis as follows:

1. The channel width on the bottom half of each frame picture (*Figure 3-4*) was estimated in the analysis. The channel width on the grey lines in *Figure 3-4* formed a width data set which was used for determining the representative channel width in step 2.
2. Instead of using the simple mean value of the width data set from step 1, the third quartile of the width data in a normal distribution was considered the representative channel width of this frame picture. The third quartile width value means 75 % of the width data lies below this value. In such a way, small values close to the vessel were filtered out.

Another significant issue in the analysis is the definition of channel width, as the points considered as channel edge affect the channel width estimation. The principle of detecting the channel edge is also presented in *Figure 3-4 - Figure 3-6.* The picture of the channel shows the collected points from the channel edge on a series of grey lines that are vertical to the vessel's centerline. The pink dots display the solid edge with high contrast, which is generally between open water and ice edge. The blue dots mark the location of the low contrast dividing line (e.g., cracked ice boundary). When considering the blue dots, there is a risk to detect the border between the water flushed on ice and dry ice.

The channel width was estimated based on the pink dots for tests with channel width much wider than the vessel's beam (e.g., level ice tests). As shown in the picture below, the estimated width can be considered slightly conservative. Nevertheless, it could provide a relatively reliable comparison among different tests using the same data processing procedure.

The channel width was also estimated based on the blue dots for the tests with the channel width close to the vessel's beam, in the channel tests. These test videos show that a large amount of broken ice was accumulated at the channel edge, causing the estimated distance between pink dots much smaller than the vessel's beam. Hence, the distance between the blue dots is preferable.

The channel boundary in the analysis was selected carefully based on the frame pictures of each test.

The results (*Chapter 4*) are presented as added channel widening, δ, which represents how much wider the channel width is than the vessel's beam, i.e., the channel equally wide with the vessel's beam (24 m) corresponds to the added channel widening δ = 0 m. The target value of 8 m refers to the aimed 32 m wide channel (8 m = 32 m – 24 m. The standard deviation presented in Chapter 4 Results is the deviation of δ in the test, see the variation of red line in *Figure 3-7*.

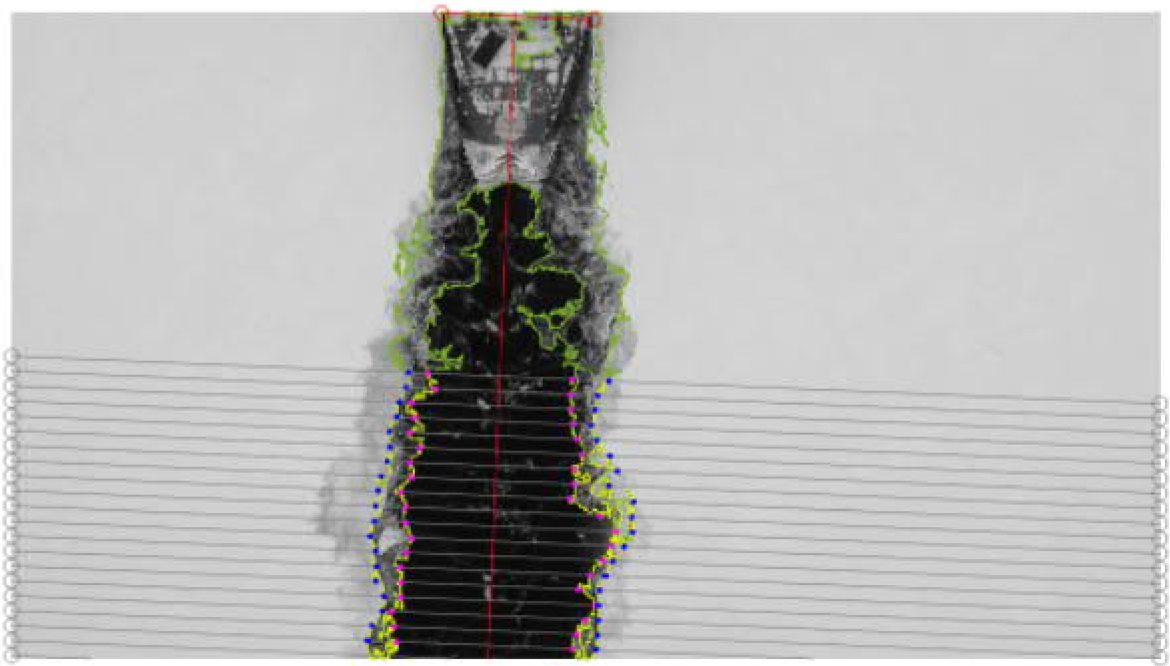

Figure 3-4: The channel width was analyzed in each frame picture. Each grey line drawn in the channel picture corresponds to one "measuring order" in the Figure 3-5 with the title of "Test 4, frame 22".

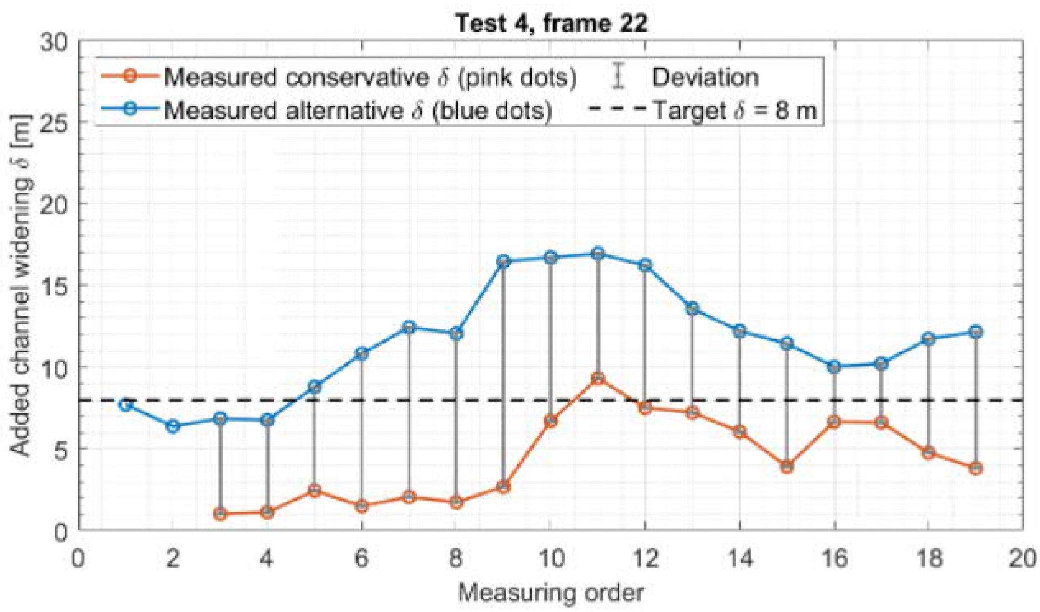

Figure 3-5: The red and blue dot lines refer to the added channel widening δ calculated from a distance between pink dots (blues dots) in the frame picture (*Figure 3-4*) reduced by the vessels' beam (24 m).

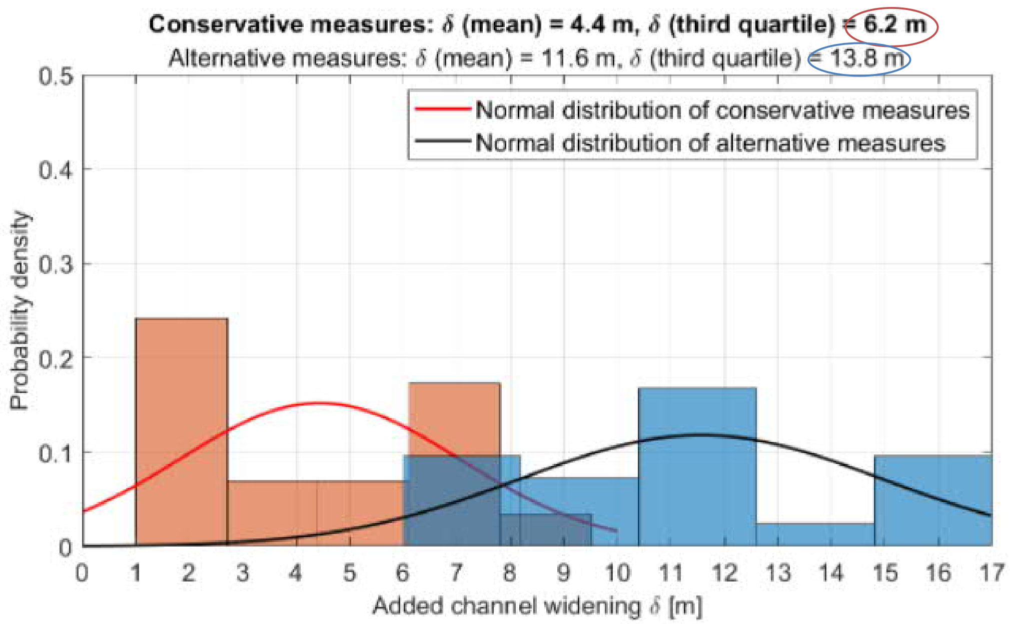

Figure 3-6: The δ data on the red (blue) dot line is assumed to follow normal distribution, as shown in the figure. Note that the limited number of data points influences the visual appearance of the histogram. The third quartile of the distribution of δ data is used in the analysis. In the level ice tests, the conservative value (third quartile) marked by a red circle on the title was preferred.

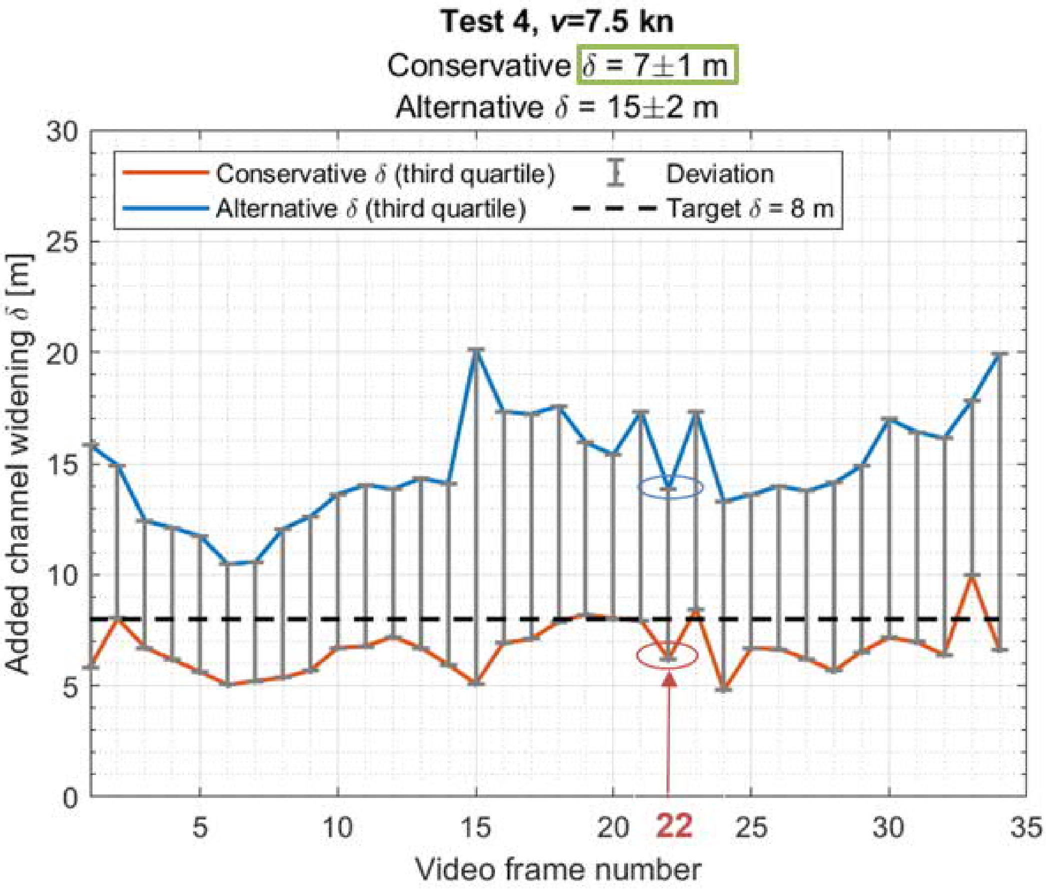

Figure 3-7: Test 4 final analysis to determine the representative estimated channel width based on the third quartile value from each frame picture using the same analysis illustrated in *Figure 3-4 – Figure 3-6* for frame 22. Added channel widening δ marked in *Figure 3-6* on the video frame number 22 are 6.2 m (red, conservative) and 13.8 m (blue, alternative), corresponding to the values in the red and blue circles in this *Figure 3-7*. The representative estimated channel width is marked by a green rectangle, for instance, δ =7±1 m for Test 4, which is used in the final analysis in *Chapter 4*.

3.7 VESSEL MEASUREMENTS

During the tests, the most critical data was collected from the command bridge displays in a test diary.

4 RESULTS

4.1 CREATING A WIDE CHANNEL IN LEVEL ICE

Figure 4-1 presents the results from tests in level ice ahead. The ice thickness was 47 – 59 cm with 25 – 37 cm thick snow cover. The vessel capability to create a wide channel is clearly influenced by both toe-in angle and speed.

These results are based on the conservative analysis, which is described in detail in *Chapter 3.6*. The added channel widening *δ* is based on the inner detected boundary of the channel and its deviation (see the analysis principles in Chapter 3.6).

The results from all toe-in angles, which were considered in these trials seems to follow the similar shape, in which the added channel widening is highest at low speeds, then decreases with the speed, but then again after some limit speed the added channel widening does not necessarily decrease anymore. Based on the limited number of tests it is impossible to say whether this phenomenon is substantive or is it a sum of coincidental deviation e.g., in ice thickness. However, the same seems to occur at some level with all tested toe-in angles, which encourages to assume this could be a consequence of a physical phenomenon such as waves forming when advancing at a particular speed.

Based on the test outcomes, the vessel capability to break over the target 32 m wide channel was estimated by fitting trendlines to the measured data points. This analysis indicates that the vessel hull would be able to break a 32 m wide channel in the prevailing ice conditions at speed of ~7 knots using a 45-degree toe-in angle (note: the vessel maximum speed was measured 5.1 knots with installed power) and at speed of 5 knots using 30 degrees toe-in angles. The toe-in angles of 15 degrees did not remarkably improve the channel widening performance.

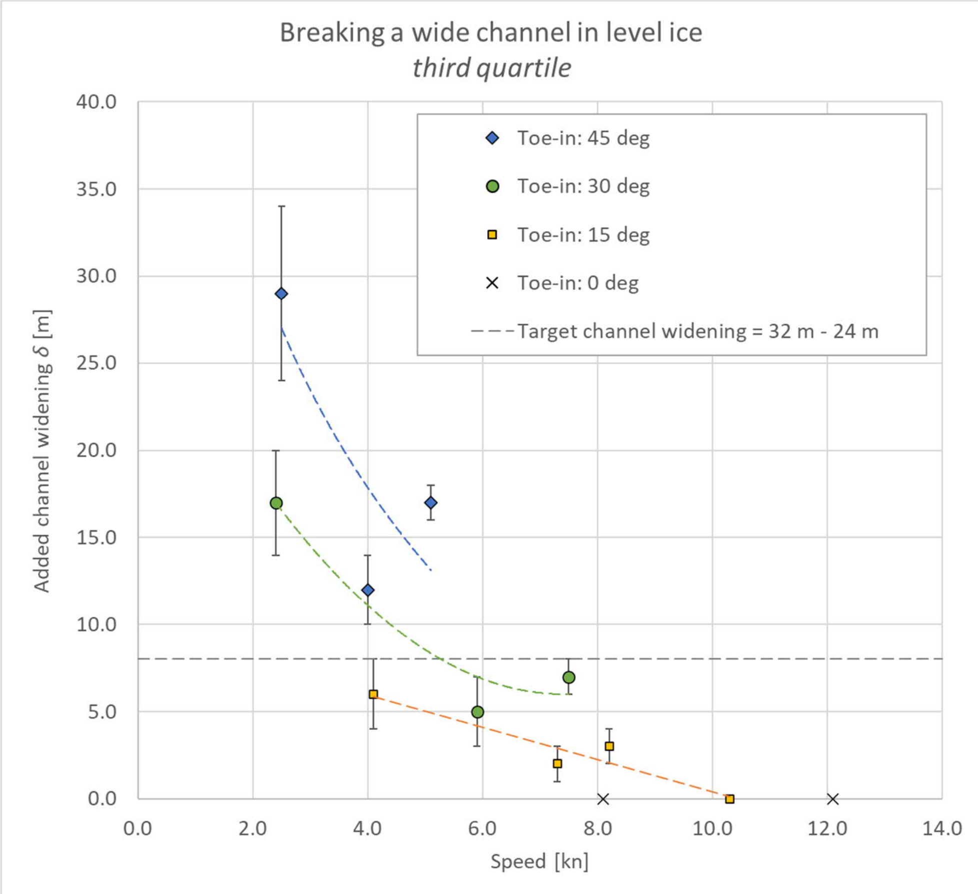

Figure 4-1: Channel widening capability in level ice, ahead, at different toe-in angles and speeds (conservative analysis). The error bar corresponds to the standard deviation of channel width (see the analysis principles in Chapter 3.6; e.g. deviation of the red line in Figure 3-7).

4.2 WIDENING AN ICE CHANNEL

Figure 4-2 presents the vessel capability to widen its own channel using relatively high toe-in angles. There is significant variation in the test results, which might be a consequence of the varying ice conditions. However, applying toe-in angles in own channel seems to make the channel significantly wider than channel width after breaking level ice with no toe-in angles. Moreover, it indicates that the vessel could maintain a high speed in an own channel while operating with high toe-in angles.

These results are based on the alternative analysis, which is described in detail in *Chapter 3.6*. The added channel widening *δ* is based on the outer detected boundary of the channel. The deviation presented in the result describes the variation of *δ* over the frame pictures within each test.

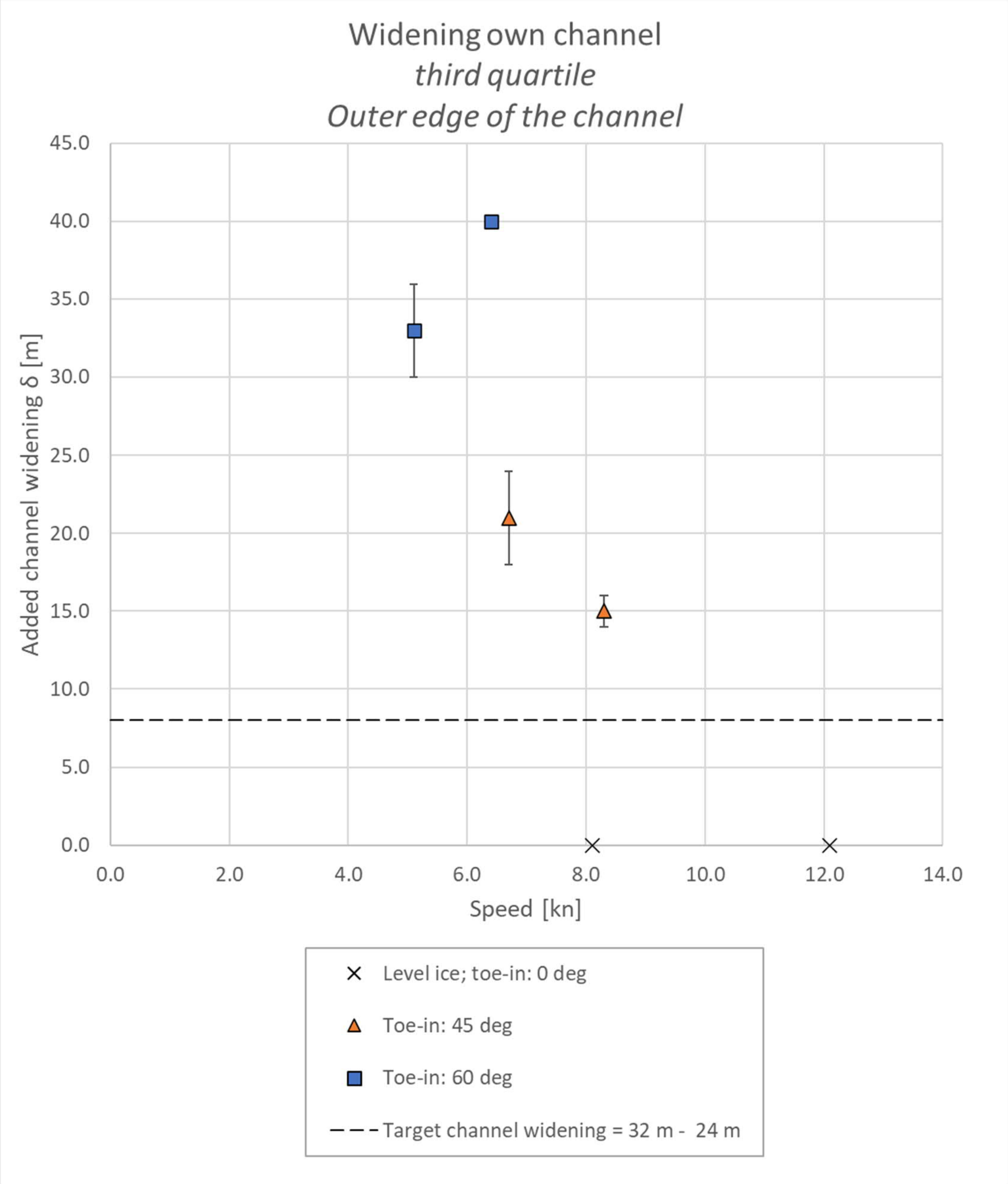

Figure 4-2: Vessel capability to widen own channel with different toe-in angles and speeds (alternative analysis). The error bar corresponds to the standard deviation of channel width (see the analysis principles in Chapter 3.6; e.g. deviation of the red line in Figure 3-7).

5 OBSERVATIONS DURING THE ICE TRIALS

Besides the actual test results, some interesting observations were done during the trials.

- When toe-in angles were applied to break a wide channel, it was observed that the created channel was remarkably clean from ice pieces compared to test with no toe-in angle, see *Figure 5-1*.

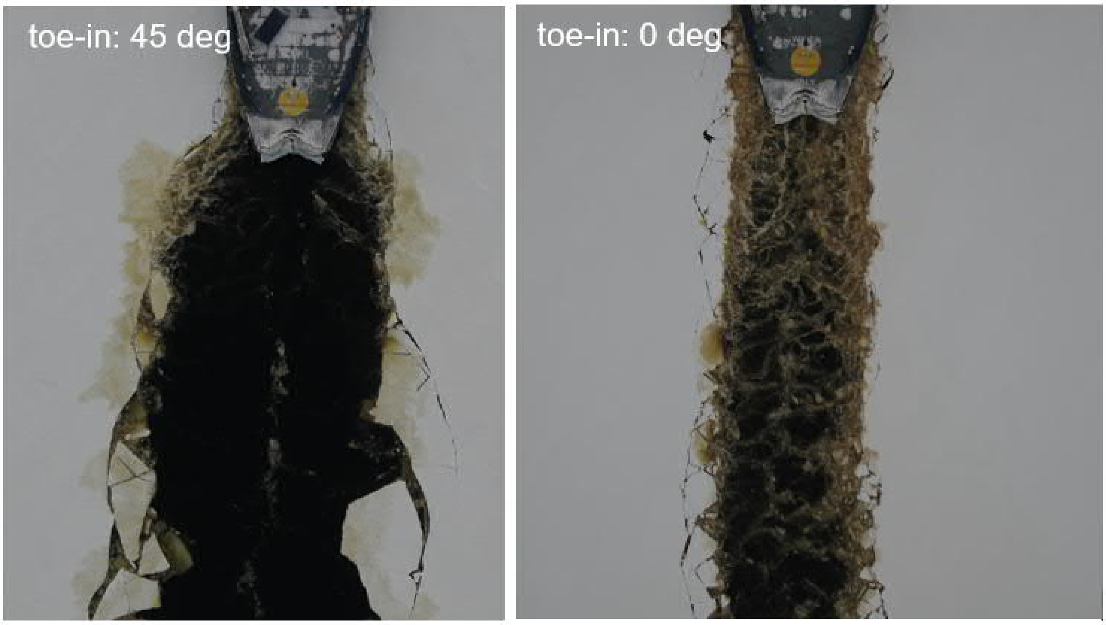

Figure 5-1: Picture in left shows the channel behind the vessel in Test 2 and picture in right Test 8

- When the toe-in angles were applied in operations ahead, no substantial vibrations were observed

- The created channel edge is not even, but it varies irregularly with the longitudinal coordinate. Considering the event of a wide vessel being assisted, it is possible that a temporary narrow spot in a channel would not remarkably slow down a vessel as the overall channel is wide enough.

- There were several cracks as far as 10 m away from the channel edge. These cracks were detectable only when walking on the ice and they are not visible in the analysis based on the video (see *Figure 5-2*). This observation may support the hypothesis that the Polaris capability of breaking a wide channel is based on the initiated cracks.

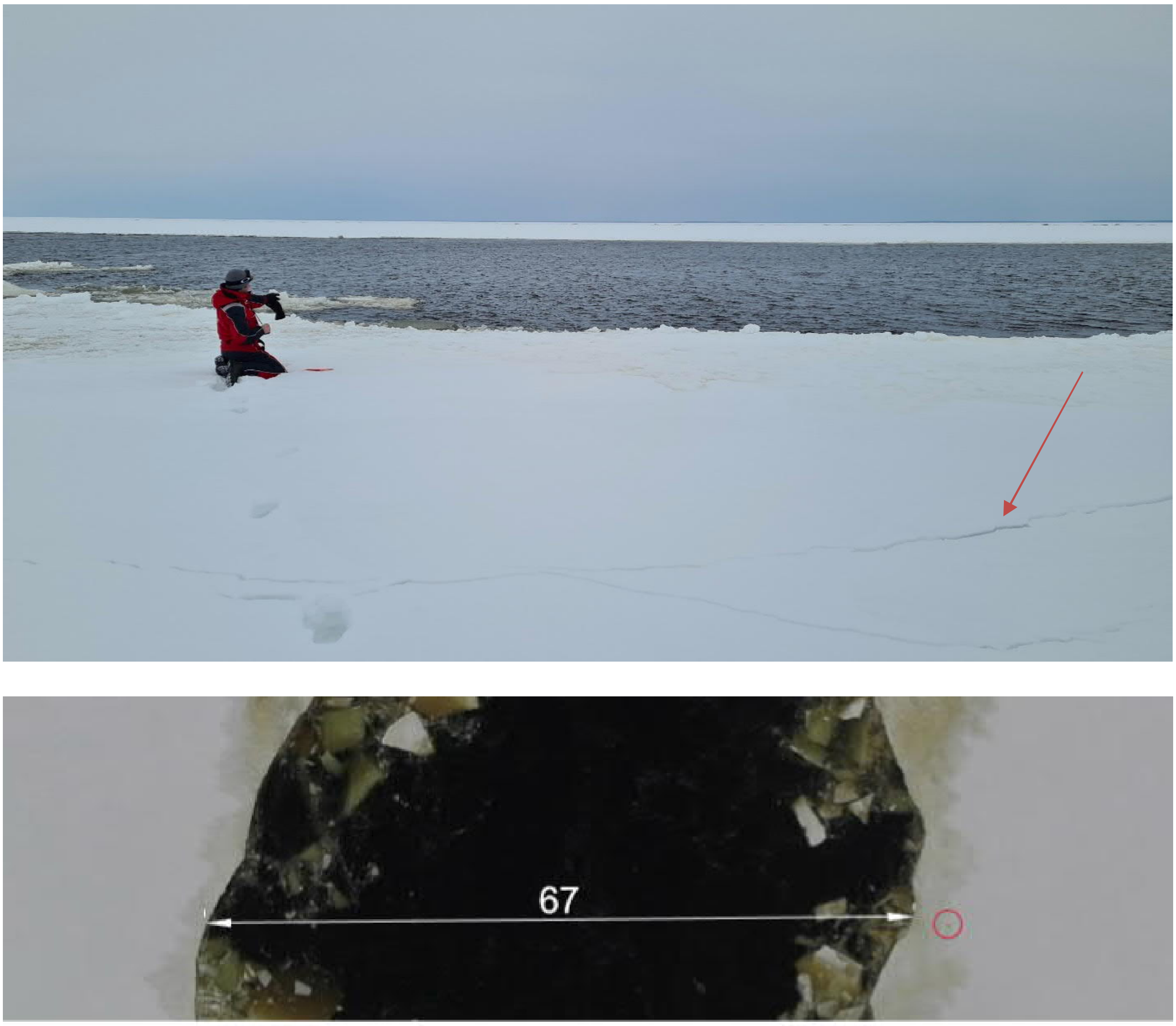

Figure 5-2: There were cracks significantly far from the channel edge, which were not visible in the video analysis, see the pictures representing the same location.

6 DISCUSSION

Polaris is able to break a wide channel at a relatively high speed utilizing stern thrusters in toe-in angles. Similar behavior has been investigated related to a few other vessels equipped with azimuth thrusters, but the channel widening has not been reported to be as effective as it is with Polaris.

This is a very interesting finding. A possible explanation for Polaris exceptional capability to break wide channel might be that the channel widening is caused by cracks, which are induced by the vessel bow, after which the thruster flow in toe-in angles disengage the ice pieces from the channel edge.

The generalizability of these results is subject to certain limitations because the tests in full scale always include uncontrollable factors. For instance, the ice was relatively thin and strong, and the ice was covered with remarkable thick and uniform snow cover. Therefore, further research should be undertaken to investigate the influence of ice thickness and strength on the vessel capability to break a wide channel.

7 CONCLUSION

The icebreaker Polaris capability to break a wide channel was investigated on ice trials on March 2021 in the Bay of Bothnia. The objective was to investigate the stern thrusters' toe-in angle and vessel speed influence on the width of created channel.

The test outcomes indicate that

- Ahead, the operation is most successful at relatively high toe-in angles and slow speeds
- Ahead, the channel width of 32 m is exceeded both with toe-in angle of 30 deg and 45 deg at 5 knots speed (also maximum speed with the power installed in prevailing ice condition and at 45 deg toe-in angle)
- Ahead, the channel created with toe-in angles of 45 deg at slow speed is wider than channel created with toe-in angles of 30 deg

Although the current study is based on a relatively small number of tests, the study certainly adds to our understanding of Polaris capability of applying toe-in angles to make a wide channel.