Forty three years of ice model testing in Finland

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ABSTRACT

Ice model testing is relatively new field of activity compared to open water testing, which has been going on over hundred years. The first laboratory for testing ships in ice was established in Leningrad in 1955.

In the middle of the 1960ies when oil had been found in Alaska, North Slope, the need emerged to study the possibility to transport the oil to the market with tankers through the North-West Passage. An existing 106000DWT tanker - SS Manhattan was chosen to be modified to do the job, see Figure 1. The design of the modification of the tanker was done by Wärtsilä Shipbuilding in Finland as they had already gained experience from building icebreakers both to the Subarctic and Arctic conditions.


Figure 1, SS Manhattan in the Arctic

At the same time during the planning of the full-scale experiment, Esso (Humble Oil), put the question on table whether the performance of the vessel could be modelled in an ice model basin. The idea was to study the possible consequences and alterations to the design when thinking of the future vessels. This turned out to be the start of ice model testing in Finland.

There has been basically two entities performing model tests in ice in Finland, namely Wärtsilä/Masa-Yards/Aker-Yards/Aker Arctic and Helsinki University of Technology (today Aalto University). The first one has had three laboratories mainly concentrating testing of ships. The latter operates a large 40m x 40m basin for testing of offshore structures and manoeuvring tests of large ship models.

PRIVATE LABORATORIES

First laboratory, 1969-1983

The Wärtsilä Icebreaking Model Basin, WIMB, was ready for testing in the end of 1969, see Figure 2. The ice modelling technique was adopted from the Arctic and Antarctic Research Institute, AARI, of Leningrad, USSR. The ice used for model was produced from high saline basin water (10-20‰) by spraying at first once fresh water on to the basin water surface. This sprayed water formed first tiny crystals, which started to grow crystals vertically downwards forming the bulk part of the ice. The top of the ice had a 2-3mm thick hard upper layer and 10-60 mm thick softer part, see Figure 3, Enkvist 1990. The maximum ice thickness that could be grown daily with this method was 65mm. Soon after WIMB was constructed two other institutions also built new facilities. The existing model basins for testing in ice in the early 1970ies are shown in Table 1.

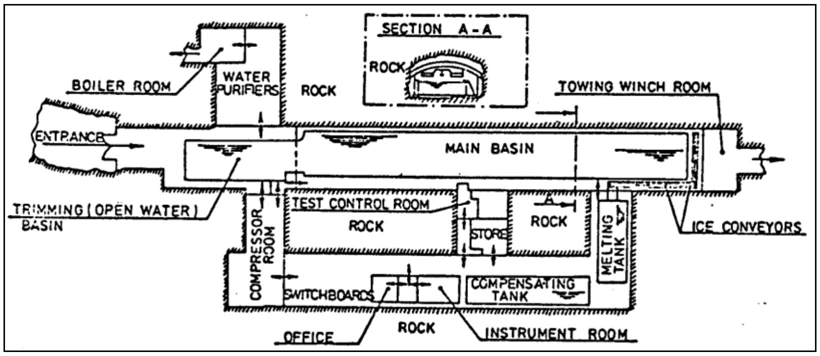

Figure 2, Layout of Wärtsilä Icebreaking Model Basin, WIMB

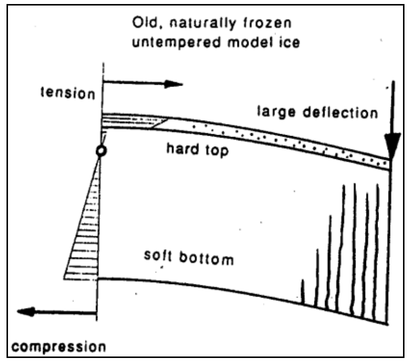

Figure 3, Ice used at WIMB

Table 1, Ice model basins in the early 1970ies

Year	**Location**	**Owner**	**Length (m)**	**Width (m)**	**Depth (m)**
1955	LENINGRAD, USSR	Arctic and Antarctic Research Institute	13.4	1.85	1.1
1969	HELSINKI, FINLAND	Wärtsilä Helsinki Shipyard	50.0	4.8	1.15
1970	COLUMBIA, USA	Arctec Inc.	18.3	2.4	1.2
1971	HAMBURG, W-GERMANY	Hamburgishe Schiffbauversuchsanstalt	30.0	6.0	1.2

The first years of the new facility were mainly used to gain experience to calibrate the model scale results with full scale measurements. A that time WIMB had the experience of six (6) ships tested in full-scale and correlation tests were done quite significantly to improve the capability of making prognoses for vessel performance in ice. Among the first calibration tests, the development of hull forms for post Manhattan era was in full swing. A lot of work was directed also for traffic in the Great Lakes. Views of the WIMB are in Figures 4 and 5.

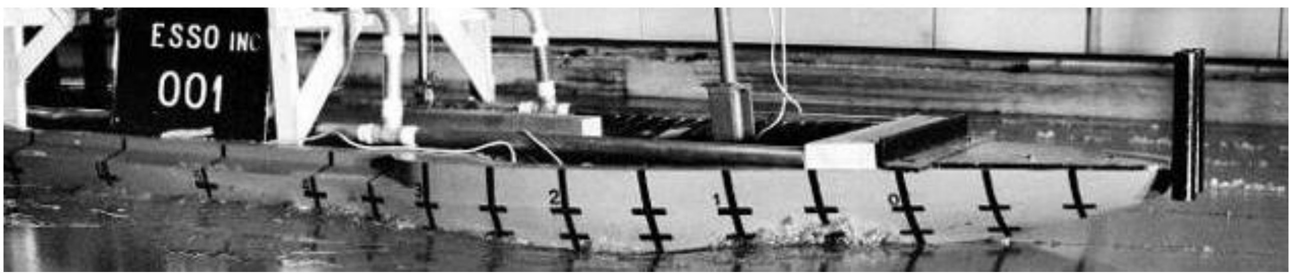

Figure 4, The first model in the basin, SS Manhattan

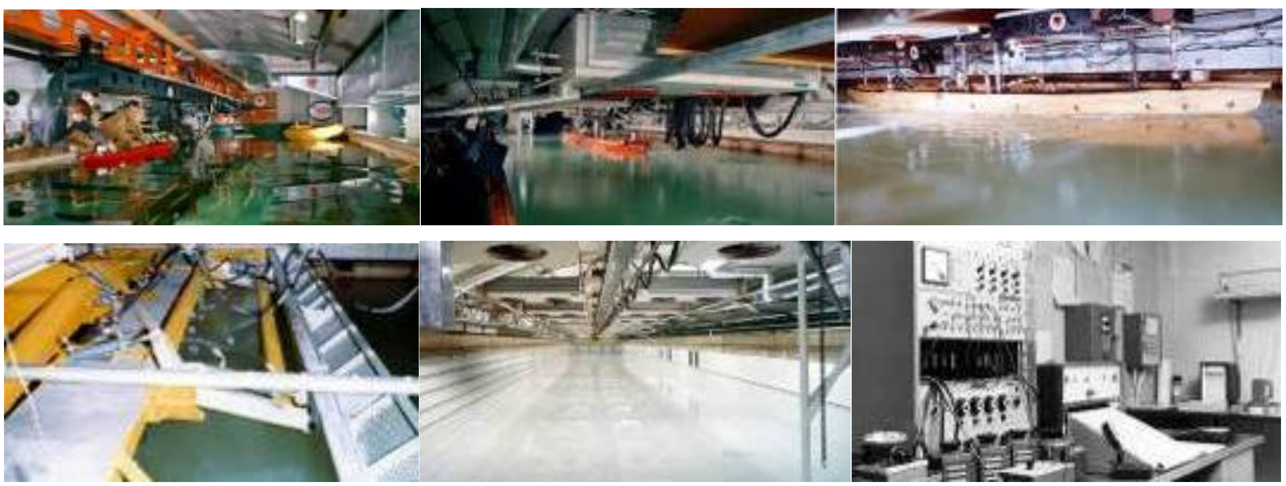

Figure 5, Views of WIMB

The first vessel developed utilizing ice model tests was the Baltic Icebreaker Urho and altogether 5 units were built (Atle, Sisu, Urho, Frei, and Ymer). In the 1970ies the icebreaker development continued to bloom. In addition to the Urho-class a number of built vessels were developed utilizing ice model testing, see Table 2. The vessels can be seen in Figure 6.

Table 2, Ships developed at WIMB

Year	Type	Name	Units
1971-74	BALTIC ICEBREAKER	Urho-class	5
1974-81	ARCTIC ICEBREAKER	Sorokin-class	4
1975-78	RIVER ICEBREAKER	Chechkin-class	6
1977-78	BALTIC ICEBREAKER	Mudyug-class	4
1979-82	RIVER ICEBREAKER	Evdokimov-class	7
1979-82	ARCTIC CARGOSHIP	SA 15, Norilsk-class	18
1980-81	BALTIC ICEBREAKER	Otso-class	2
1981-82	ARCTIC ICEBREAKER	Taymyr-class	2

Figure 6, Vessels developed: Urho-, Sorokin-, Chechkin-, Mudyuk-, Evdokimov-, Norilsk -, Otso- and Taymyr-class

In addition to the vessels mentioned in Table 2, WIMB was active in the market through WADAM (Wärtsilä Arctic Design and Marketing) mainly serving development projects for the Baltic Sea like:

- tankers
- ferries
- LNG- carriers
- anchor Handling vessels
- tugs
- bulk carriers
- RO-RO carriers
- Coast Guard cutters
- lash/container carries
- fishing vessels
- coastal road ferries
- dredgers

During the existence of WIMB also different kind of research projects were carried out:

- friction between ice and ship hull coating
- air bubbling system development
- propeller loads
- operational docking tests
- offshore structures
- modelling development

In the 1970ies in addition to testing ships in full-scale, some effort was put to study ice conditions in two major areas:

- Canadian Arctic Islands, for LNG export
- Antarctica, development of new support vessels

The saline ice used in WIMB was far from perfect. The specific weight, thickness and flexural strength could be properly modelled but the ice having dual structure, hard thin top and flexible thicker bottom, resulted in very flexible and elastic behaviour. The broken ice cusps were typically very large, more than double, and this made for instance tests with propulsion rather difficult as excessive milling took place. The ice resistance as such was rather well under control, especially when WIMB had more and more real full-scale data as well. Figure 7 shows one example of model test full-scale test correlation from the middle of the seventies. The agreement with model and full-scale results is quite good in smaller ice thicknesses, but in 1.2 m thick ice the model tests gave somewhat lower values. During the early years the friction between the model surface and ice was a big question. Tests were done typically with two different surface treatments and together with full-scale tests and finally it was concluded that the friction coefficient μ = 0.16 would be closest to compare a new hull surface.

At WIMB all the tests were done as towing tests mostly without propulsion. Some tests were done with propulsion to identify problems with complex hull forms. Very seldom self propulsion was used, mainly in certain operational tests like docking and offloading. In 1980 the story of WIMB started to be complete as in Wärtsilä the decision was made to build a new facility above the ground. The new facility was to be commenced in 1983.

During 1969 - 1982 altogether 100 model test series were performed and reported. Simultaneously the full-scale activity was continued as well and some 65 test programmes were carried out and reported in different parts of the icy world. At the same time the Soviet Union started to develop the traffic in the Northern Sea Route (North East Passage).

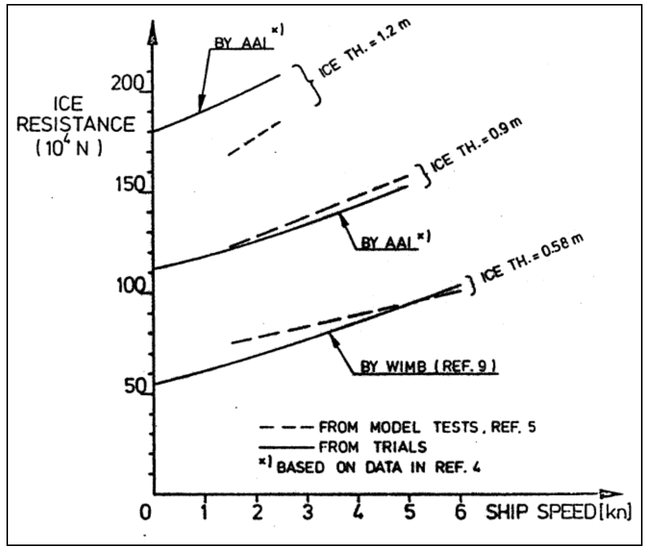

Figure 7, Test result correlation at WIMB with Moscow class icebreaker, Mäkinen 1975

SECOND LABORATORY

Wärtsilä Arctic Research Centre, WARC, 1983-89/Masa-Yards Arctic Research Centre, MARC, 1989-2005

The new laboratory, which was based on the experience from the first one, was targeted to be the leading facility in the world. A new type of model ice was a dream to be developed as the old technology did not match the need for more accurate results. The facility was to be more of a research centre than just a laboratory. The idea was to also start basic research on topics supporting the research and development activity. In the laboratory a lot of the experience from the first pioneering laboratory was taken into account.

The test basin needed to be bigger as ships have grown in size and large offshore structures were to be tested. A special cold room, temperature down to - 60°C, was included in the design. The new facility was inaugurated in February 1983. The layout of the facility is in Figure 8. In the 1980ies an Arctic exploration boom in the Beaufort Sea was on and also more activity was planned for the Northern Sea Route (NSR) north of Russia and the opening of the new basin happened at right time.

Bigger basin

The main dimensions of the basin were:

- Total length 77.3 m
- Length of ice sheet 60.0 m
- Water depth 2.3 m
- Breadth 6.5 m

Better ice modelling

Simultaneously with the construction of the new facility a project to develop a new type of model ice was started. The result of this was the Fine-Grain ice (FG-ice).

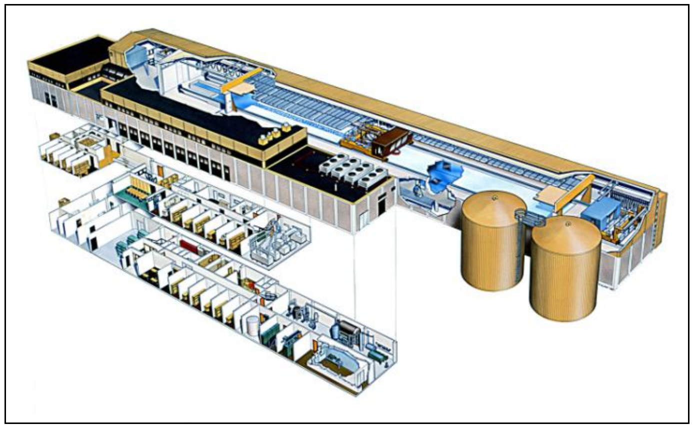

Figure 8, WARC/MARC facility

This ice differs from everything available quite remarkably, see Figure 9. The idea is to spray saline (1.3-1.5%) basin water into the cold air and the water droplets will partly freeze before they reach the water surface. This is done with the help of an auxiliary carriage running back and forth on rails along the basin. Each roundtrip of the carriage produces a 2-2.5 mm layer of soft granular white ice slush.

The carriage is run as long as the required thickness is received. Later the material is hardened with the cooling process during the night. Varying the temperature and time the ice properties can be controlled in a wide range. The FG-ice was developed through a master's thesis by Seppo Mäkinen, 1982.

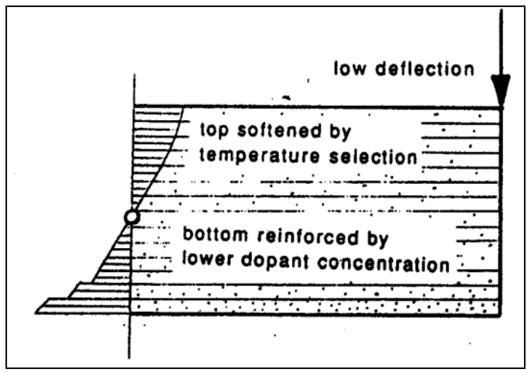

Figure 9, Structure of laminated FG/FGX model ice

The planned activity at WARC was four-fold:

- Basic research - post graduate student research
- Finnish government research quote
- Wärtsilä's own R&D
- Commercial work

The advantages of FG-ice are:

- Better brittleness/less elastic
- Ice breaks into realistic pieces
- Better ice control
- Strength properties are more realistic

The FG-ice was further developed in 1986 by adding the possibility to adjust the salinity of the spray water for each layer.

Facility above ground

The new facility was built by the Bay of Vanhakaupunki (Old Town) near the original birth place of Helsinki. Figure 10 illustrates some views in the WARC facility.

The major achievements during this time are listed in Table 3. Most of the activities at WARC were related to in-house development projects for vessels intended to be built at Wärtsilä's own shipyards.

During the 1980ies the practices in testing took a vast leap towards more realistic tests. The following development took place:

- behaviour of model ice, development of FG ice
- towed propulsion tests became a standard
- first steps to self propulsion tests were taken
- friction control

Figure 10, Wärtsilä Arctic Research Centre, WARC, views

Table 3, WARC activities in the 1980ies

Year	Project Name	Year	Project Name
1982-83	FG-ice	**1987**	Sea train concept
1986	FGX- ice	**1987**	River train concept
1984	New bow of MV Arctic	**1987**	Bow concept development for L. St. Laurent
1983-84	GVA 5000 Arctic Semi-submersible	**1987-88**	Cylinder impact project
1985	Push-Barge system	**1987-88**	Development of Aurora Australis
1985-86	Arco ALNGS	**1987-88**	Development of James Clark Ross
1986-87	Wärtsilä BOW	**1988**	Lake Saimaa Icebreaker
1985-86	100000 DWT tanker for IHI	**1987-93**	Small Icebreaker for IHI
1983-87	Friction panel project	**1987-88**	Mingeo research icebreaker
1985-87	Ice deflecting bottom ribs	**1987-88**	IB Karhu nozzle and open propeller
		1988-89	IB Sampo propeller ice loads

Some of the projects carried out at WARC are shown in Figures 11.

Figure 11, WARC projects

The oil exploration activities in the 1990ies were somewhat quieter than during the previous decade. Activities concentrated on environment conditions including ice. Still more and more model tests were directed to offshore structures.

In the late 1980ies Wärtsilä, ABB and the Finnish Board of Navigation started the development of new azimuthing electric thrusters; AZIPOD. This development led to Double Acting Ship (DAS) concepts, a new way of thinking of icebreaking. The DAS concept opened completely new possibilities in icebreaking practices, where in the eighties there was the feeling that everything has been invented already. The FGX model ice with more realistic behaviour allowed to study better also propulsion characteristics.

In the eighties the FGX model ice was found very successful and the technology was adapted in two other laboratories (AORC of Helsinki University of Technology and KSRI, Krylov Shipbuilding Research Institute in St. Petersburg) on licence arrangement. MARC also delivered the full set of laboratory equipment for KSRI and supervised the installation. During the nineties the number of personnel grew to 15 and the activity produced annually positive results. The number of ice sheets tested annually in the ice basin varied between 35 and 70.

In the early 1990ies the continuation of activity was very uncertain as the whole continuation of shipbuilding in Finland was. However, ownership changes and acquisition of the facility guaranteed that development work could continue, i.e. 90% of all work from 1990 on was commercial. Also in the 1990 started the research for studying ice conditions, especially in The Russian Federation, see Table 4.

Table 4, MARC field activities in the 1990ies

Year	Project Name
1990-92	Barents Sea ice studies
1989-91	Sakhalin ice research
1992	Sakhalin icebreaker tour, IB Krasin
1992-99	Pechora Sea JIP ice studies
1995-2000	Ob Bay ice studies
1993	Kara Sea ice studies

Table 5 illustrates the major testing activities in the 1990ies and Figure 12 shows some of the projects carried out. During the 1990ies the practices in testing were further develop to fulfil requirements from the market. The following development took place:

- self propulsion tests became a standard
- operational tests, free model with a captain on board
- coupled tests, a ship model and an offshore structure model tested simultaneously
- models with azimuth thrusters, running astern
- tests in moving ice (level ice)

Table 5, Major testing activities in the 1990ies

Year	Project Name
1988-97	Azipod development
1989-90	Ice rubble formation for Chuchki Sea
1989-90	Early concepts for Sakhalin platforms
1991-92	Next generation Baltic Icebreaker
1991-92	Fast ferry, Telakka 2000
1993	Azipod in ridges
1993	Development of river IB Röthelstein
1994	IB Healy
1993-97	60000 dwt Arctic tanker for IHI
1995-2000	Development of Double Acting Tankers
1996	Offloading in the Arctic
1996-98	Development of Oblique Icebreaker

Year	Project name
1997	Development of IBSV Arcticaborg
1998-99	R&D of ships for Finnish inland canals
1999-2000	Development of barge system for the Caspian Sea
2000	Development of MT Tempera
2001-03	Tanker parametric development
2002-03	Harbour icebreaker development
2003, 04	Optical cable project
1998,2002	Great Lakes Icebreaker project
2003,2005	Development of MV Norilskiy Nickel
2003-05	Ice class tankers, multiple projects
2003	Rescue operation from a platform
2003	Development of Fesco Sakhalin

In 1999 to 2004 it was very uncertain how the activity would continue if at all. The parent company Kvaerner Masa-Yards was facing tough times and through several ownership arrangements Kvaerner disappeared from the picture and Aker started to penetrate more actively into the shipbuilding world. Finally in 2004 it was decided to establish a new separate company and build a new testing facility

During the 1980ies a lot of the ground work was done to improve the reliability of model tests in ice. The FGX ice allowed moving from simple towing tests little by little towards self propulsion tests and real world in ship operation.

Figure 12, MARC projects

The scaling of model tests results has taken a big leap from studying the different components of ice resistance to straight scaling by λ to power three. The correlation between model tests and full-scale ship tests has improved remarkably. In Figure 14 there is the model scale – full-scale comparison of icebreaker Otso, Figure 13. Icebreaker Otso is the standard calibration model and quality control tests are run on regular basis

The facility of WARC/MARC had to be abandoned and taken down as Helsinki City had developed housing plans to the whole area. The deadline was set to be summer 2005

Figure 13, IB Otso

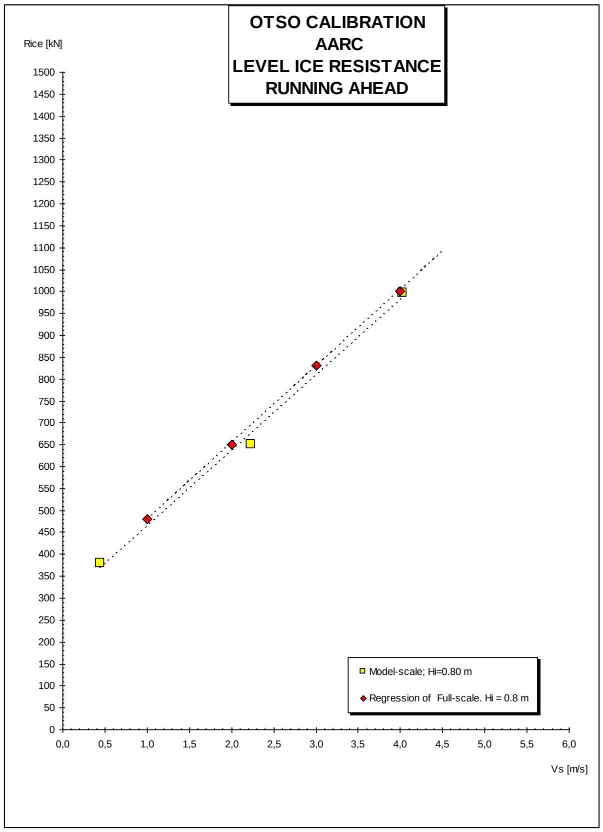

Figure 14, Model scale – Full-scale correlation of IB Otso

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THIRD LABORATORY

Aker Arctic Technology, AARC, 2006 - >

The new technology company Aker Arctic Technology Inc started operation in January 2005. Simultaneously the construction of the new facility in Vuosaari Marine Business Park was started. The new facility was ready for start-up in February 2006 and the AARC personnel moved in. Figure 15 illustrates the layout of the facility and a view in the neighbourhood. The new facility was inaugurated on March 6, 2006. Views of the new facility are in Figures 16. The operation started quite fast and the facility was fully operative by mid March 2006.

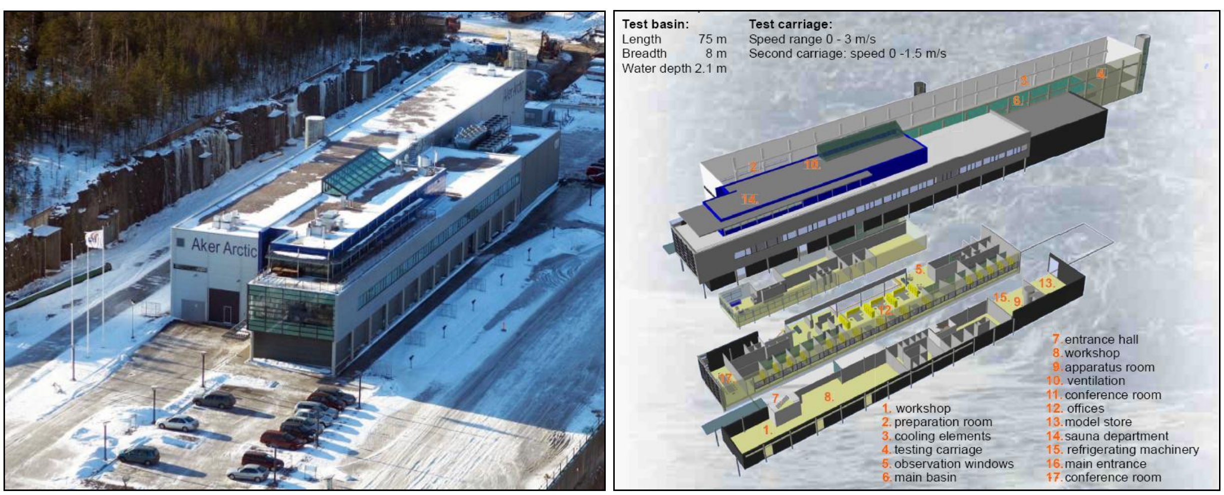

Figure 15, New AARC facility

Figure 16, New AARC facility, interior views

Simultaneously as the new facility was taken into operation the model test market seemed to increase. During the previous 15 years the number of annual test days varied between 35 and 70. In 2006-2008 the test days by different test types is listed in Table 6.

In 2008 the activity increased especially around oil exploration structures and vessels. Also different types of icebreakers started to be active again, especially in the Russian Arctic. As the new facility was taken into use, the activity of AARC also was broadened. In addition to testing services and concept development, also more profound project services were taken into the menu. The personnel increased by eight (8) experienced engineers raising the total number of personnel into 26 in 2006. Today Aker Arctic has 40 employees Projects executed in 2005-2012 are listed in Table 7. Figures 17 show some of the projects executed in 2006-12.

After the third laboratory was inaugurated in 2006 the testing practices in have been developed further. The following development has taken place:

- preparation of very thick and brittle ice, thickness up to 200 mm.
- wireless data signal transfer
- wireless video signal transfer, one screen with multiple video signals
- radio controlled models
- two ship models operating in the basin simultaneously

Table 6, Different tests in 2006-2012

Type of project	2006	2007	2008	2009	2010	2011	2012
Ice class tankers	38	21	10	12	-	-	-
Icebreaking LNG carriers	20	9	4	8	4	27	59
Icebreakers	-	5	13	17	28	8	14
Offshore structures	6	20	27	14	-	17	9
Drill ships	-	-	23	10	15	-	-
Oil spill (old basin)	4	-	-	-	-	-	-
Cargo vessels	1	13	11	3	4	14	-
Ferries	-	-	-	-	3	6	-
Antarctic vessels	-	-	-	-	4	5	6
Coast Guard vessels	-	-	-	-	3	-	3
Calibration/ice development/ R&D	8	-	10	9	10	9	16
Offshore service vessels	3	9	12	28	29	7	6
Total	**80**	**77**	**110**	**101**	**100**	**95**	**113**

Table 7, Projects in 2005 - 2012

Year	Project Name
2006	Norilskiy Nickel full-scale tests
2006-09	Norilskiy Nickel sister ships
2006	Modification of Frontier Discoverer, drillship
2006	Drilling platform Kulluk modification
2005-09	Arctic Tanker Vasily Dinkov (3 units)
2005-09	Arctic Tanker (2 units)
2008	Jack-up model tests
2008	North star arctic island model tests
2007-08	Multipurpose platform service IB for Estonia,
2008	Arctic Anchor Handling vessel for Shell
2008-09	Arctic Anchor Handling vessel for Transatlantic
2006-09	Arctic LNG carriers
2006-09	Arctic Cruise vessel

Year	Project Name
2006-09	Various drillship projects
2008-09	Aurora Borealis drilling vessel, model tests
200	Arctic Offshore Patrol Ship
2006-08	Arctic Container carrier
2006-11	Arctic Ore Carrier for Baffinland iron mines
2008-09	Arctic PSV for Shell
2011	Aurora Borealis, Slim Design
2006-12	AARC 101-114 vessel series
2006-12	Caspian 50t tug, Basic design & testing
2012	Oblique icebreaker concept design
2012	Canadian Polar Icebreaker
2012 - >	Chinese Polar Research vessel
2005 - >	Trimaran development
2007->	Ship operation simulator for ice

Figure 17, AARC Projects

After learning the possibilities in the new facility it was time to search the possible limits of the facility. Till 2006 the upper limit of ice thickness had been c. 100 mm. This limit was stretched at first to 150 mm and then to thicknesses above 200 mm. It was somewhat surprising that the properties of the ice could be preserved. Brittle thick ice with flexural strength of around 20 kPa was a bit of surprise, see Figure 18. The making of such ice required a bit different approach and it takes 3-4 days, practically a whole week, to prepare just one ice field. This is still very much under development and the method is not yet considered to be a standard procedure.

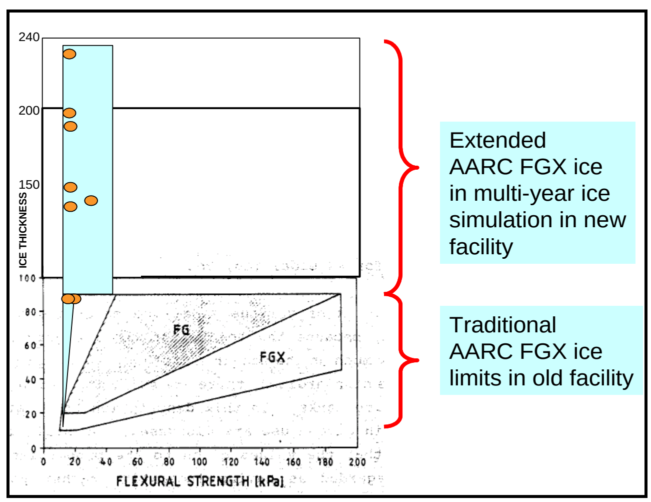

Figure 18, Extended limits of FGX model ice manufacturing

STATE OWNED LABORATORY

History (Kostilainen et al. 1987)

The other ice model basin in Finland state owned and hosted by Aalto University, formerly the Helsinki University of Technology. The basin was originally a clear water manoeuvring and sea keeping basin, which was constructed in 1970. Later large clear water clear water manoeuvring and sea keeping basins with highly advanced equipment at that time were built in Sweden and Norway and therefore it was decided to reconstruct the basin to an ice model basin. The design concepts for the rebuilding were:

- Possibility to model test in ice
- To maintain the capability to conduct clear water manoeuvring and sea keeping tests
- Flexibility for various types of tests with ships, floating and fixed offshore structures, at low and medium speed

A couple of years before the reconstruction of the University basin started, Wärtsilä Arctic Research Centre WARC had developed the fine grain ice, which was produced by spraying. It was decided to adopt the same ice making method to the new university basin with the difference that WARC used salt as a dopantd in the water but HUT decided to use ethanol. The new ice model basin was ready to operate in 1988.

Worlds larges ice model basin

The Aalto University ice model basin is still the largest in the world. The water surface area is 40 m x 40 m with the maximum depth of 2.8 m. It is equipped with an X-Y-carriage, which allows the use of the whole basin area. According to the original plan to maintain the possibility to conduct sea keeping tests, there is a 40 m long wave generator in one side of the basin. Thus the basin is also the only basin in the world, where tests can be done together with ice and waves.

The university basin has always concentrated mainly on scientific research, but also commercial work has been done. Aker Arctic has been co-operating with Aalto University and typically the tests, which need more ice surface area, is performed in the Aalto ice tank. This kind of tests are for example manoeuvring tests in ice and ice vaning tests with large sea bottom moored floaters or drill-ships, for instance the manoeuvring tests of the Great Lakes Icebreaker were performed at the Aalto University basin, see Figure 19.

Figure 19, Great Lakes Icebreaker, GLIB, manoeuvring test

TESTS WITH OFFSHORE STRUCTURES

Most of the tests done during the past 43 years have been with ship models. However, as the offshore development has been moving towards the icy regions, more and more tests have been done to figure out what kind of facilities are needed and are suitable for operations in ice. In the first laboratory, WIMB, only a few tests with structures were done. This was because the model ice was not very suitable for testing structures with vertical elements. After the FG-model ice was introduced in 1983, it was found that the ice material was also quite suitable for testing structures. Since then all kinds of structures from bottom founded jackets through floating semi-submersibles to drill ships have been tested. Some of the tests are shown in Figures 20.

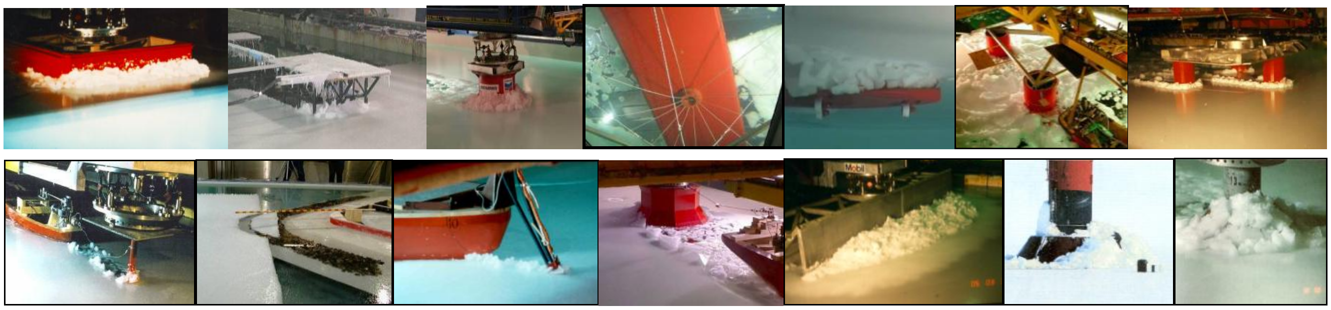

Figure 20, Structure tests

CONCLUSION

In spite of the fluctuation of the behaviour of the industry, the capability and capacity of performing model tests in has been preserved and developed. During the last 4-5 years the need to test ships and structures in ice model testing facilities has increased. One of the initiatives has been the climate change as the operation window in the Arctic gets longer which gives new possibilities for oil and gas exploration and so far experimental transit passages along the Russian Northern Sea Route. During the past decades, also analytical methods have been tried to develop. However, ice model tests are still the most efficient way to estimate the behaviour of ships and structures in various ice conditions. During the last years new laboratories have been built. We also need to know and understand the real behaviour of ships and structures. Ice model tests together with full-scale measurements are truly needed.

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