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ICE GOING CAPABILITY OF A SMALL UNCONVENTIONAL VESSEL IN THE KASHAGAN FIELD

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ABSTRACT

The North Caspian Sea area and the Kashagan Fields can be considered a unique environmental scenario which has assumed a strategical importance during this decade owing to the development of off-shore structures. In this paper is shown the analysis on ice going capability of a small unconventional vessel (an Ice Breaking Emergency Evacuation Vessel operated by Agip KCO) operating in the Kashagan field, equipped with two pulling type thrusters.

The open water performance has been investigated in the shallow water tank of Krylov Shipbuilding Research Institute. The purpose of the research in the hydrodynamic basin was to study the influence of shallow water and ultra shallow water on resistance, propeller-hull interaction and propulsion. Some bow and stern shape variants have been tested in ice model tank in order to verify the ice going capability of the vessel and to reduce ice resistance.

Three campaigns of full scale trials in ice were performed in North Caspian Sea during the last years. The scope of these trials was to verify the maximum performance of the vessel and to investigate its operative limitations. Ice going capability and manoeuvrability were widely investigated for different ice thickness and flexural strength. A great deal of further analysis and measurements, not discussed in this paper, were also performed during the trials as vibration on hull, machineries and propulsor, torsional vibration and hull strain measurements (strain gauges).

The overall result of the conducted study is identification of the allowable combination of ice thickness and flexural strength to achieve a minimum safety speed. Moreover, some operative recommendations are given in order to preserve the vessel from any damage (failure) and assure safety operations.

INTRODUCTION

Agip KCO, operating in the Kazakhstan sector of the North Caspian Sea, is the Owner of the Ice Breaking Emergency Evacuation Vessel (IBEEV) fleet, see Figure 1.

These vessels are designed to evacuate personnel from offshore oil installations in emergency situations and in a hydrocarbon/toxic environment. The IBEEVs were designed for navigation in first year ice. Their general characteristics are summarized in Table 1.

Table 1. Vessel characteristics.

Class	DNV + 1A1 ICE 1B DAT (-30°C)	Power	Diesel-electric, 2 x 800 kW/1500 rpm each
Length overall	45.10 m	Main propulsion	2x Schottel Rudderpropeller-SRP 550, 550 kW/1500 rpm.
Breadth, moulded (main deck)	8.00 m	Propeller diameter	1400 mm
Depth moulded (main deck)	3.60 m	Steering	SCHOTTEL Steering System type SST 900
Operative draft	2.10 m	Bollard pull	11.5 t
Displacement at summer draught	568.1 t (sp. Gr. 1.025 t/m3)	Special features	pull-propeller
Deadweight at summer draught	174.8 t	Operation area	Caspian Sea
Evacuees (seated) 328 Evacuees (on litters) 10			
The vessel is able of overload power for limited periods (650 kW – 118%) during ice "break out" operations.			


Figure 1. Ice Breaking Emergency Evacuation Vessel.

A three-year project started on 2007, involving Navalprogetti S.r.l. Naval Architects & Marine Engineers – Trieste (Italy) and Krylov Shipbuilding Research Institute Federal State Unitary Enterprise – St. Petersburg (Russian Federation). Scope of the research was to identify the actual performance envelope of IBEEVs.

In order to achieve this goal, a number of activities was planned and executed, encompassing theoretical modelling, calculations, model tests in hydrodynamic laboratories and full-scale testing in ice (the last carried out in the Agip KCO area of operation).

These activities were developed by Navalprogetti in co-operation with the following departments of Krylov Shipbuilding Research Institute (KSRI):

- Ice Tank Department – Kirill E. Sazonov – Head of Ice Tank;
- Ship and Offshore Structures Department – Valery M. Shaposhnikov – Head of Department;
- Icebreaker Design Department – Valery A. Belyashov – Chief Designer.
- Shallow Water Tank – Leonid Schmietchlin – Head of Shallow Water Tank.

OPEN WATER PERFORMANCE IN SHALLOW WATER TANK

Navalprogetti ordered KSRI to perform a calm water model test program for the IBEEV operating in deep and shallow water with stock thruster units.

The goal of these experimental tests was to identify the effects of shallow and ultra-shallow water on resistance, hull-propeller interaction and vessel performance under a given shaft horsepower with two stock thruster units for propulsion. The model of the vessel was manufactured at a scale 1:10.

The resistance and self-propulsion tests were carried out in the Shallow Water Towing Tank of KSRI under speed-ahead conditions. The model tests in open water were performed for one value of the draft *(T*=2.4 m) at three values of water depth (i.e., *H* = 15.9, 4.8, 3.5 m) in full scale, defined quasi-deep, shallow and ultra-shallow water, respectively).

The diagram of Figure 2 allows to identify the values of achievable speed in quasi-deep water, and also at H=4.8 m and H=3.5 m depth. These values are summarized in Table 2.

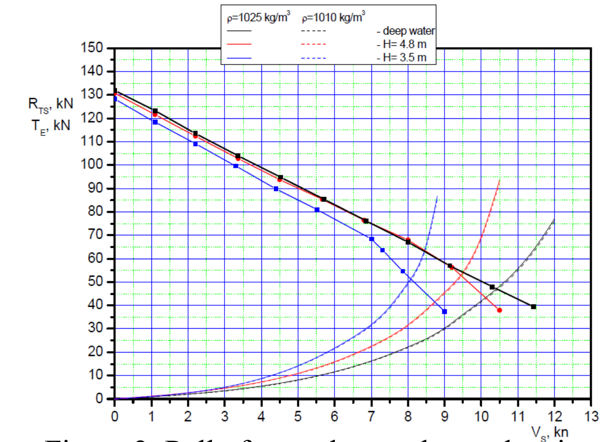

Figure 2. Pull of propulsor and vessel resistance as a function of speed.

Engine power P_S, [kW]	Water depth H, [m]	H/T [-]	Vessel speed V_s, [kn]	Froude number F_n, [-]
2*550	H=15.9	6.63	10.4	0.25
	H= 4.8	2.00	9.4	0.23
	H= 3.5	1.46	8.1	0.20

Table 2. Values of achievable speed of IBEEV.

When sailing in shallow water, the hydrodynamic resistance of IBEEV increases as well as its running draft and trim (see Figures 3 and 4).

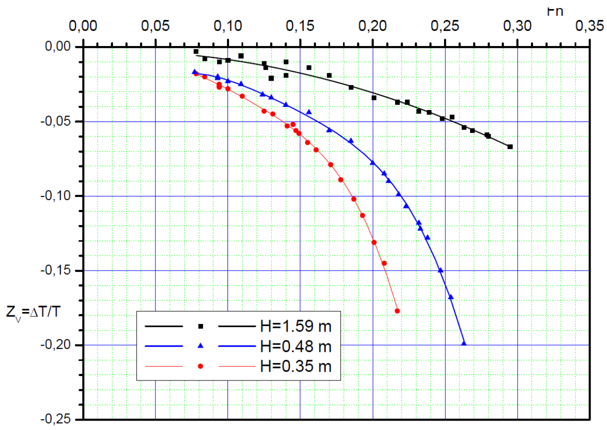

Figure 3. Sinkage of the model versus Froude number, F_n, at three values of water depth (values in model scale). Z_v<0 – sinking.

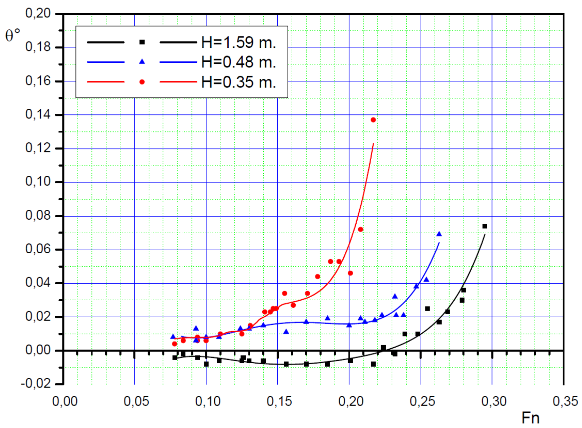

Figure 4. Trim of the model versus Froude number, F_n, at three values of water depth (values in model scale). θ°>0 – trim by stern.

When propellers were working, the vessel trim by the stern increased even more as a result of pressure redistribution. In some cases the vessel hull knocked against the basin bottom.
Figures 5 and 6 show the draft variation at amidships versus Froude number and the running trim angle versus Froude number, respectively, for a propeller model's rotational speed n=18 rev/s in case of extreme shallow water *H*/*T*=1.46.

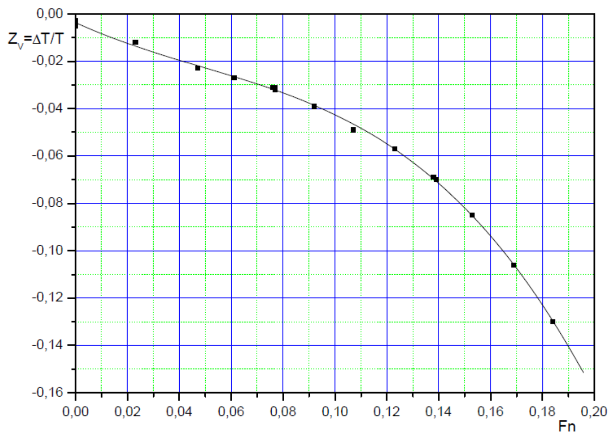

Figure 5. Variation in IBEEV vessel midship draft vs Froude number in the condition of extreme shallow water H/T=1.46, during propulsors operation with rotational speed of the propellers n=18 rps.

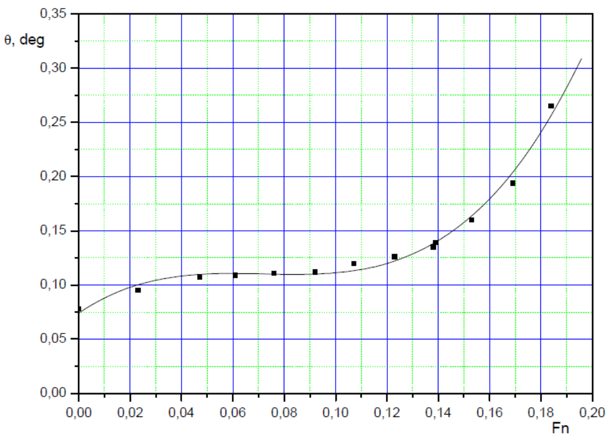

Figure 6. IBEEV vessel running pitch angle vs Froude number in the condition of extreme shallow water H/T=1.46, during propulsors operation with rotational speed of the propellers n=18 rps.

Analysis of results shown above suggests a vessel speed limitation in ultra-shallow water conditions. As an example, at *Fn* = 0.2 and *H*/*T* = 1.46 (V_s=8.1 kn) the maximum underkeel clearance decrease is about 0.5 m, this means that underkeel clearance decreases from 1.1 m to 0.6 m in full scale, with risk of knocking against the sea bottom even in moderate sea states.

FULL SCALE TRIALS IN ICE

The purpose of the IBEEV full-scale trials performed in 2008 – 2010 was to determine the parameters of ice-going capability and manoeuvrability of the vessel and their compliance with specific requirements. The following parameters were determined during full-scale experiments:

1. Maximum ice-breaking capability of the vessel in continuous level ice when vessel moves with forward and backward speeds.
2. Vessel gyration radii when vessel moves with forward and backward speeds.
3. Possibility of the channel break-out for the vessel.

Specialists of AGIP KCO (Kazakhstan), Navalprogetti and KSRI organized and carried out the full scale trials in 2008, 2009 and 2010.
KSRI specialists performed ice coring and related measurements (i.e. thickness, temperature and salinity). Above mentioned values were used to determine the ice strength values basing on the methodology adopted in Russia.
In 2008 the tests were performed in spring ice cover, the strength of which was approximately 200 – 250 kPa. The results obtained in these tests could not be applied to conditions of winter navigation. Therefore the decision was taken to perform repeated trials in winter ice. Such tests were performed in 2009 and 2010, when ice bending strength was 560 kPa on average.

The tests were carried out in level ice with different thicknesses found in the vicinity of the artificial islands A and D.
The programme, reported in Table 3, to determine ice power performance and controllability, was conducted during full scale trials 2010.

Table 3. Program for ice going capability and maneuverability (FSTI 2010).

Mode No.	Mode name	Start	Finish	Description
6	Forward speed, level ice	12:30	12:34	Thickness 49-55 cm 100% power
7	Forward speed, level ice	12:34	12:37	Thickness 49-55 cm 118% power
13-14	Gyration, forward speed	14:11	14:17	Thickness 43-51 cm, 100% power, δ =15°, δ = 30°
15-16	Gyration, forward speed	14:17	14:21	Thickness 43-51 cm, 118% power, δ = 30°, δ = 45°
18-20	Backward speed, level ice	15:21	15:25	Thickness 43-51 cm, 80,100 and 118% power. No movement.
26	Channel leave, forward speed	16:51	16:55	Thickness 48-50 cm, broken ice 100% power, δ = var.
Note: δ=Deflection angle of PPU.				

In addition to modes above, investigations of the vessel hull ice strength as well as individual tests were conducted to study hydrodynamic characteristics of the propellers at bollard pull.
When each of the test modes was performed, the following parameters were logged in:

- IBEEV movement speed, which was determined using standard devices through GPS signals, as well as using portable GPS receiver.
- Power absorbed by each of the podded propulsion unit (PPU) motors and shaft revolution rates. These measurements were done by Navalprogetti specialists.

Ice thickness and ice physical and mechanical properties were measured for each test mode by Agip KCO specialists.

Besides other navigation instruments, two GPS systems were used during sea trials to record vessel position and speed. Both the GPS were mounted on aft wheelhouse top; their measurements were recorded with a frequency of 1 Hz.
The graph in Figure 7 shows an example of recording history.

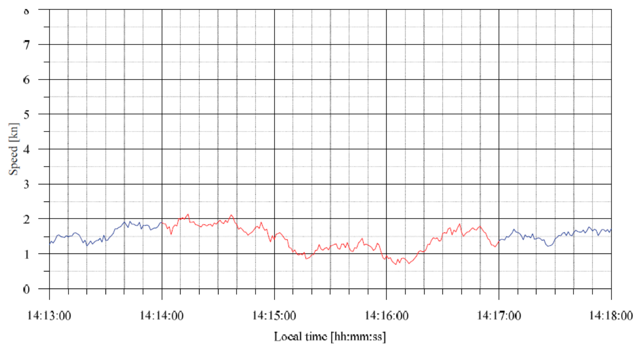

Fig. 7. Speed measurement during gyration test
(50 cm – ice flexural strength 560 kPa).

The ice-breaking capability diagrams (see Figures 8 and 9) were generated on the basis of the data obtained in these tests. The IBEEV ice-going capability was assessed using these curves.

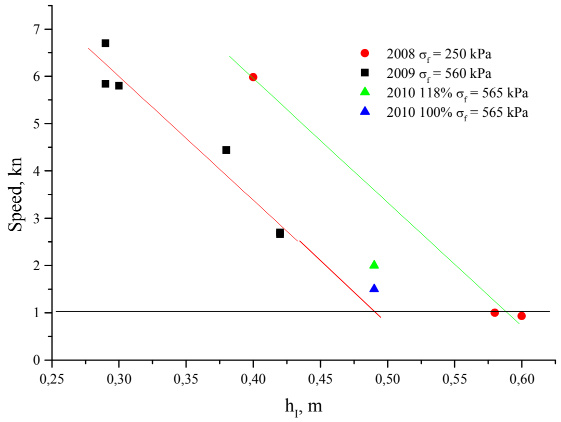

Figure 8. IBEEV ice-breaking capability as derived from 2008, 2009 and 2010 test results.

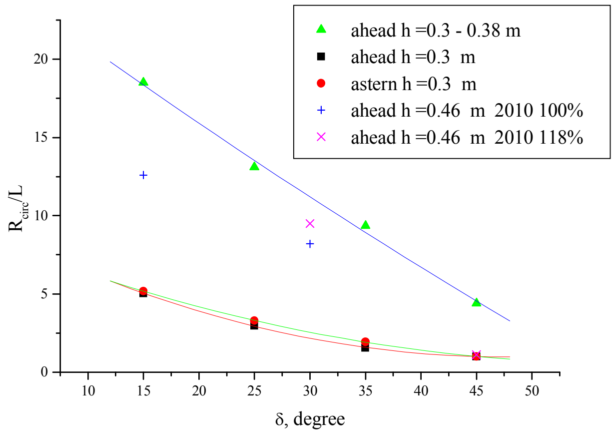

Figure 9. IBEEV relative gyration radius in winter ice when moving with forward and backward speeds (2008 and 2009 test results).

The IBEEV ice breaking capability when running astern was also checked: the recorded parameters were much lower than those found when sailing ahead. The obtained data show that the IBEEV movement with backward speed is complicated both in cold winter and in heated spring ice.

Figure 9 presents the dependences of the IBEEV relative gyration radius versus thrusters' angle. These data show that ice strength characteristics have significant effect on IBEEV maneuvering capability when moving with forward speed. When moving backwards the ice maneuverability parameters practically depend little on both the ice strength and its thickness. Such behaviour is determined by the poor form of the original stern shape.

Further measurements were performed during the trials in 2010, namely:

- stbd thrusters steering;
- port thrusters steering;
- accelerations on thrusters machinery and electrical motor (8 uniaxial accelerometers);
- video recording (4 water-proof camera);
- stress measurement with strain gauges (25 strain gauges);
- torque measurements (2 torsiometers).

MODEL TEST IN ICE TANK

The purpose of the experimental campaign in the ice tank was to improve the hull forms of IBEEV by reducing ice resistance under different ice conditions, as well as to study the ice-going qualities when varying the absorbed power level. The tests were performed running both ahead and astern at full-scale draft of 2.4 m and in shallow water at depth of 3.5 m in level ice with a thickness of 0.4 and 0.6 m (model scale 1:10).

The full-scale trials demonstrated a poor performance of the vessel when running astern. This behaviour is due to a too high transom longitudinal angle (49°). Figures 10 and 11 show the present stern shape of IBEEV.

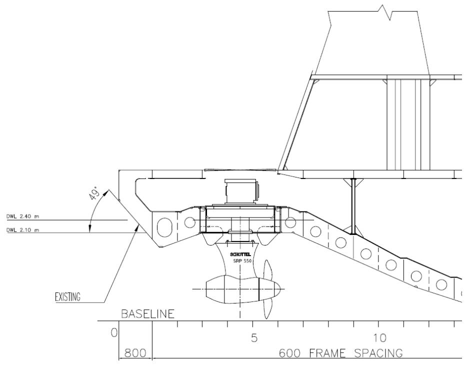

Figure 10. Section of the actual stern of the IBEEV.

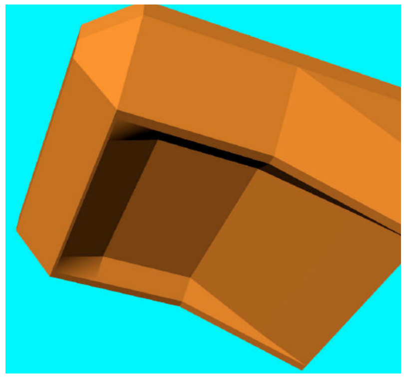

Figure 11. 3D View of the actual stern.

In order to improve the ice going capability running astern, Navalprogetti designed two stern variants with different longitudinal transom angles: the first variant has the transom angle reduced to 26° (Stern A), while the second has this angle further reduced to 16°(Stern B).
KSRI was requested to perform a number of tests in ice tank with IBEEV models having different fore and aft ends in order to select the configuration that could improve the ice going capability. The two stern variants, both with longitudinally reduced transom angles, and one bow variant with a bigger ice wedge (to include a pump jet thruster as per Owner request) were tested.

In order to compare the two variants with the IBEEV as it is, with the model running astern, towing tests without operating propeller in 0.4 m level ice thickness (full scale) were performed. The results of tests have shown that among three forms of the hull, the stern B provides the best icebreaking capability when going astern, see Figure 12. The B variant was also tested with operating propellers in 0.4 m and 0.6 m level ice (full scale).

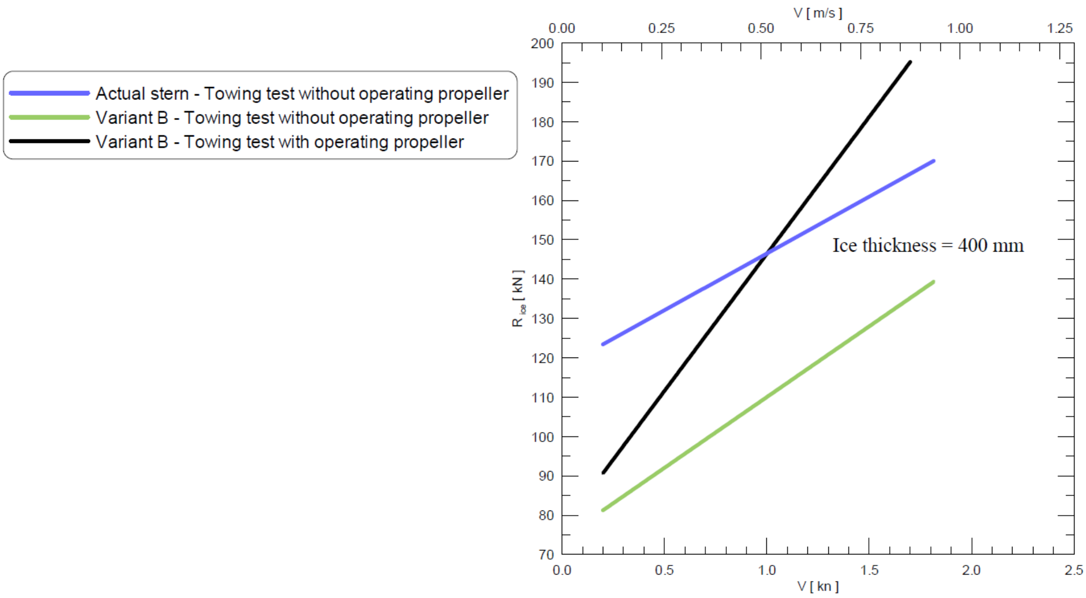

Figure 12. Comparison between resistance of the actual stern of IBEEV and the B variant.

When sailing astern in shallow water with ice thickness higher than 0.4 m, additional resistance arose because of the presence of the thrusters. In order to decrease it, the installation of an ice knife of at least 30 cm high should be adopted.

The change of the vessel fore end with the proposed bigger ice wedge has no influence on vessel's ice going capability. This means that a pump jet bow thruster installation is practicable without penalization of ice performance.

The stern variant B which gave best performance running astern is shown in Figures 13 and 14.

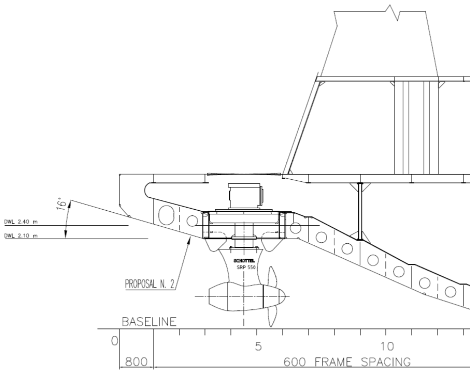

Figure 13. Profile view of the B variant stern. proposal stern of the IBEEV.

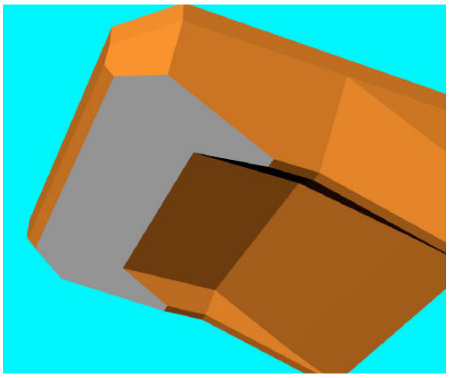

Figure 14. 3D view of the B variant.

OPERATIVE RECOMMENDATIONS

To ensure safe and reliable control of Schottel units in the Caspian Sea ice conditions, some recommendations have been developed. As a general guideline, to control the Schottel thrusters in ice conditions, the units are recommended to be controlled as carefully as possible without sharp variations of parameters. Such recommendation is given because azimuth propulsors enable the vessel to be quickly accelerated in any direction, and this capability usually leads to significant dynamic loads on propulsors affected also by high power.

Sharp manoeuvres in ice and high power parameters, as a rule, are connected with strong vibration which exerts harmful effect and can reduce service life of mechanical components. In this case, also fuel consumption would increase. Especially large turning angles, in combination with high speed of movement in open pack ice or moving in the channel, bring to strong vibrations. At the same time, these vibrations are not always perceptible on the bridge.

The general recommendations on performing different manoeuvres are presented below:

- Operations with backward speeds should be avoided, if possible, since ice going capability moving astern is worse than the one moving ahead.
- Usage of "overload power mode" (118%) allows increase of the ice going capability (IBEEV speed could be increased by 0.5 knots).
- Vessel turning is most efficient when podded propulsion units (PPU) are deflected slowly (by steps). This way of turning is recommended.
- The vessel movement with stopped propellers, including inertial motion in any ice conditions, is forbidden, both going ahead and astern, especially in hummocky and thick ice.

- When reversing, vessel speed should be restricted and should not exceed 3 knots. Vessel deceleration is recommended to be performed by deflecting of PPU inwards on 90 degrees (without reducing the revolutions and power till the vessel stops); only after the stop of the vessel, the deflection of PPU can be completed.
- It is forbidden to ram into ridges with propellers working at full power at speeds of more than 3 knots.
- When moving in thick and hummocky ice it is recommended to maintain 100% power or to use the "overload power mode" of 118%; at the same time the speed of movement should be changed and determined by turning the propulsor.
- During compression again ridge it is recommended to stop and turn the propulsor to wash away ice floes from the hull.
- It is recommended that ridges are passed through at slow speed, while performing periodic smooth change of PPU angle by 10-20 degrees at "overload power mode".

CONCLUSIONS

Analysis of the results of the IBEEV full-scale trials performed during winter seasons in 2009 and 2010, as well as the results of their comparison with data of previous full-scale trials (2008) and model experiment data, allow the following conclusions:

- Vessel is operationally capable to keep minimum speed when running ahead in unassisted condition in continuous level ice with a thickness of up to 0.5 m at any ice bending strength values not exceeding 550 kPa.
- Vessel is operationally capable to keep minimum speed in unassisted condition in continuous level ice thickness greater than 0.5 m with limitation in ice flexural strength (ice monitoring).
- Vessel is operationally capable of running ahead in unassisted condition in continuous level ice thickness of up 0.6 m at ice bending strength lower than 250 kPa.

Minimum speed required to IBEEV has been considered equal to 1 knot. The green area of graph in Figure 15 identifies the combinations of ice flexural strength and ice thickness which allow the vessel to move at the minimum acceptable speed (1 knot) running ahead in level ice.

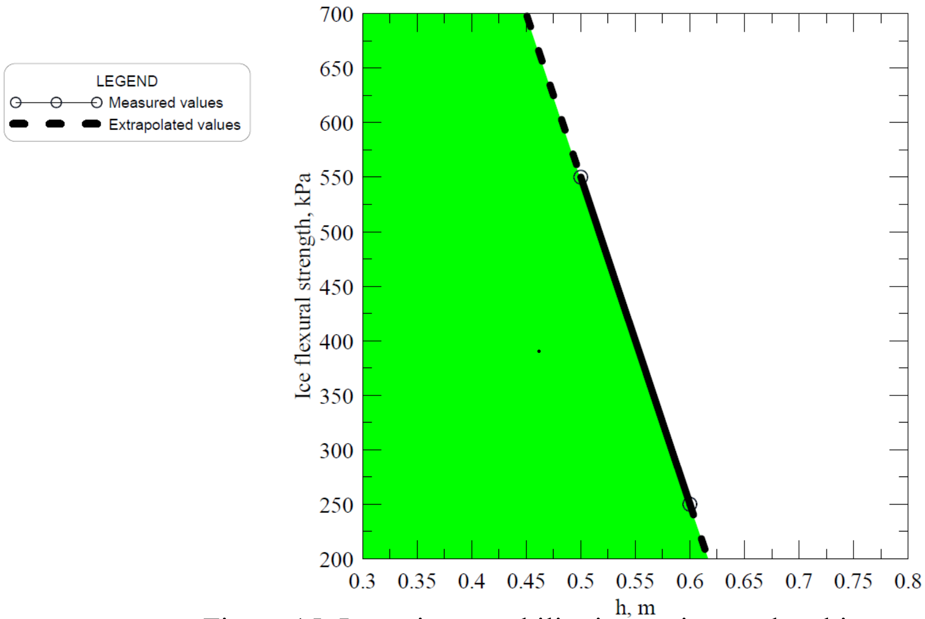

Figure 15. Ice going capability in continuous level ice running ahead for a minimum speed of 1 knot.

In order to prevent any damage to propulsors the operative recommendations given in previous Chapter shall be adopted.

Since the ice going capability running astern is quite lower than running ahead, the modification of the stern shown in Figures 13 and 14 should be adopted. It is also recommended the installation of an ice knife in the centreline plane of the aft end.

When the vessel is operating in ice free ultra-shallow water the speed should be limited in order to prevent any damage to the thrusters and to the hull due to draft and trim increase.