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Visualization of CAE-solutions of partial problems of ice navigation. Vessels passing

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Abstract

The present article is devoted to a research of ice performances jointly of the working vessels with use of opportunities of modeling and visualization of modern CAE-technologies. In this work the urgent problems of the movement and joint maneuvering of vessels in different ice and navigation conditions are considered. According to the analysis of the results of multiple CAE-modeling specific recommendations for the studied cargo fleet of different ice categories at the choice of safe passing distances, ship regulation laws, performance of standard maneuvers are made.

Keywords: CAE-system, postprocessor, finite element modeling, ice conditions, vessel, ice performances.

1. Introduction

The CAE-system (Computer Aided Engineering) is the computer technology modeling and visualizing space-time progress of the studied process. At present similar technologies find their application in different areas of knowledge: mechanics, hydro-, gas- and thermodynamics, construction, processing of materials, medicine, nuclear physics, hydrometeorology, micro and macro world etc. The basis of CAE-system is the numerical solver of systems of the differential equations describing behavior previously sampled (it is normal in the finite element formulation) areas of space (environment, body). At the same time, it should be noted that in addition to the proven numerical methods convergence of the solution here is also provided with special «artificial» program procedures, algorithms and functions.

The essentially significant stage of such technologies is the postprocessing, realizing the analysis of results of modeling by means of scientific visualization. The tools of the postprocessor are three-dimensional graphics, animation, and also the graphic processor creating different nodal and elemental space-time functions.

The whole complex of tasks of sea and river icebreakers belongs to the extensive class of deformable environments mechanics problems. In this field of modeling the first commercial CAE-systems are appeared and now remain the most reliable and therefore demanded. The basic scientific novelty of CAE-technologies by consideration of mechanics problems consists in *modeling of interaction of objects* in contradistinction to *modeling of loadings* that offer a traditional semi-empirical and the majority of numerical methods. In problems of assessment and forecasting of ice fleet qualities it allows to pass for implementation *of non-autonomous* interaction of the vessel's hull and its thrust steering complex (TSC) with ice water environment. Unlike the classical *autonomous* solutions [1-8] considering influence of only quantitatively static *isotropic environment on the vessel*, CAE-models describe the *interference* of the vessel and environment taking into account *stochasticity* of this process in space and time. As the important advantage of the CAE-analysis, it is also necessary to acknowledge the possibility of division of hydrodynamic and ice load that is unavailable to a model experiment and full-scale tests.

In the field of ice navigation there is a considerable number of private tasks of safety. Generally, they are caused by requirements of optimization of maneuvering of vessels (including joint) in different ice conditions during the short period of time (ranging from several minutes to several tens of minutes). The experience of the author showed that in such cases the forecast of safe conditions from positions of averaging of influence of set of ice arguments (as traditional solutions propose) will have a low forecast success rate [9-12]. Thus, when it is impossible to carry out full-scale tests, the alternative way of reliable forecasting of several vessels interaction in ices is the numerical experimentation with application of CAE-technologies.

To demonstrate this the author has executed a series of experiments on the basis of the models described below. In this work the LS-DYNA CAE-system adapted by authors for the solution of ice problems is used [15]. Modeling is executed using an explicit finite-element method. Predicted data for the subsequent post-processing are stored in the binary files database.

2. Modeling

Theoretical bases of CAE-modeling of problems of a sea and river ice technology (types and formulations of finite elements, models of materials, algorithms of contact interaction, finite element mesh, procedures of decrease in a resource investment of problems) are developed by the author in the monograph [9].

For the subsequent analysis several tens of discrepancy options have been calculated, the ice channel laying and dressing of vessels in different ice and navigation conditions have also been considered.

In the numerical experiments a river-sea operation dry cargo ship «Sormovsky» (project 1557; ice class «Ice-1») and the shallow-draft river icebreaker «Captain Evdokimov» (project 1191) acted as prototypes of model vessels.

In the calculations some parameters ranged. The ice thickness was 0,2-0,8 m. Its degree of size changed as a small ice cake, ice cake (the ice floes having the average size in the plan to 20 m) and compact ice. Initial distances between diametral planes of vessels were 5-60 m. The general directions of the mutually movement of vessels and their speed varied 1,0-5,0 m/s. The number of maneuvering vessels in a zone of interaction at the same time was 2-3. The orders operating them were «with pullout» (the control mode a rudder which is in addition considering the angular speed and acceleration of the vessel at turn) and «without pullout» (the control mode a rudder considering only angular displacement of the vessel at turn). The relative length and width of the ice channel (the field of a compact ice) in all options slightly fluctuated within 3,5 length and 6,0 width of the greatest vessels respectively.

The form of ice floes has no influence on the level of vessel's ice loads. Such an influence has the floes' size. In both real and virtual modeling it is common to cover the water area with rectangular «tiles» of ice sized within studied fragmentation level [1–3]. That approach makes modeling more efficient. In this work square ice floes no more than 20 m wide were used. They correspond to the small ice cakes and ice cakes in the nature.

The action of ship thrust steering complexes, hydrodynamic loads on hulls of the vessels and an ice cover have been described by nodal forces according to recommendations of work [9-12].

3. Discussion

Any safe vessels passing can be considered as the counter and parallel movement within strictly established lanes (traffic separation zones). In ices this maneuver is carried out on straight sections of ice routes only (ice channels). The level of safety of passing in this case is determined by route (leading) stability of each vessel in this ice environment and beam distance between them. The first parameter can quantitatively be evaluated through transverse displacement of the vessel and behavior of an angle of its yaw, which are directly connected with the operation of the vessel.

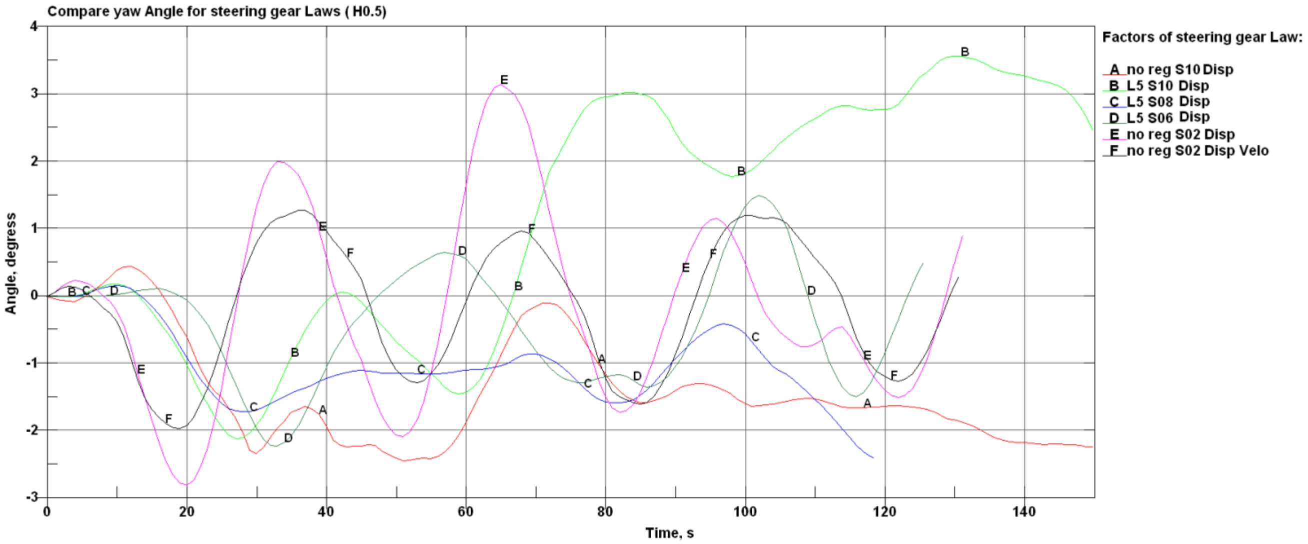


Figure 1 –Behavior of a yaw angle of the motor ship type «Sormovsky» in ice cakes (A-E - ice cake of different degree of size and concentration at the control law «without pullout»; F - ice cake concentration 2 balls at the control law «with pullout»).

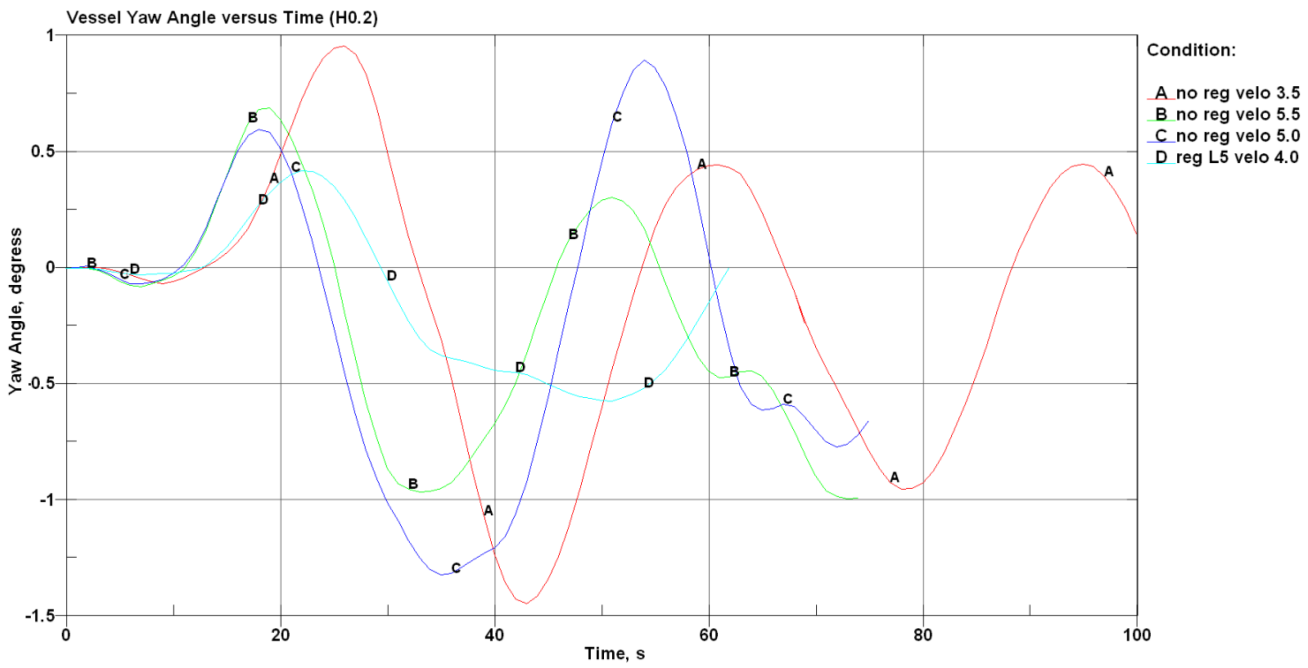
The note to fig. 1: Concentration of ices is the relation of total area of ice floes to the area of the water area covered with evenly distributed ice. It can be evaluated on a 10-ball scale: 0 - open water; 10 - compact ice.

Generally, in ice conditions the automatic driving of the vessel is unacceptably, but the human factor always brings identity in the mentioned law. The analysis of natural observations on operational yaw stability of the studied vessels [13,14] showed that for conditions of ice cakes and small ice cakes at some proven, average and almost implementable law of the thrust steering complex operation the yaw does not surpass the size of 3,0 degrees with probability of 95%. Taking this into account, at a preliminary stage the autonomous movement of vessels in ices for the purpose of working off of the control law providing full-scale confirmed parameters of their yaw was modelled. The example of CAE-assessment of route stability of the motor ship type «Sormovsky» in ice cakes 0,5 m thick at their different concentration and degree of size for several control laws is given in fig. 1.

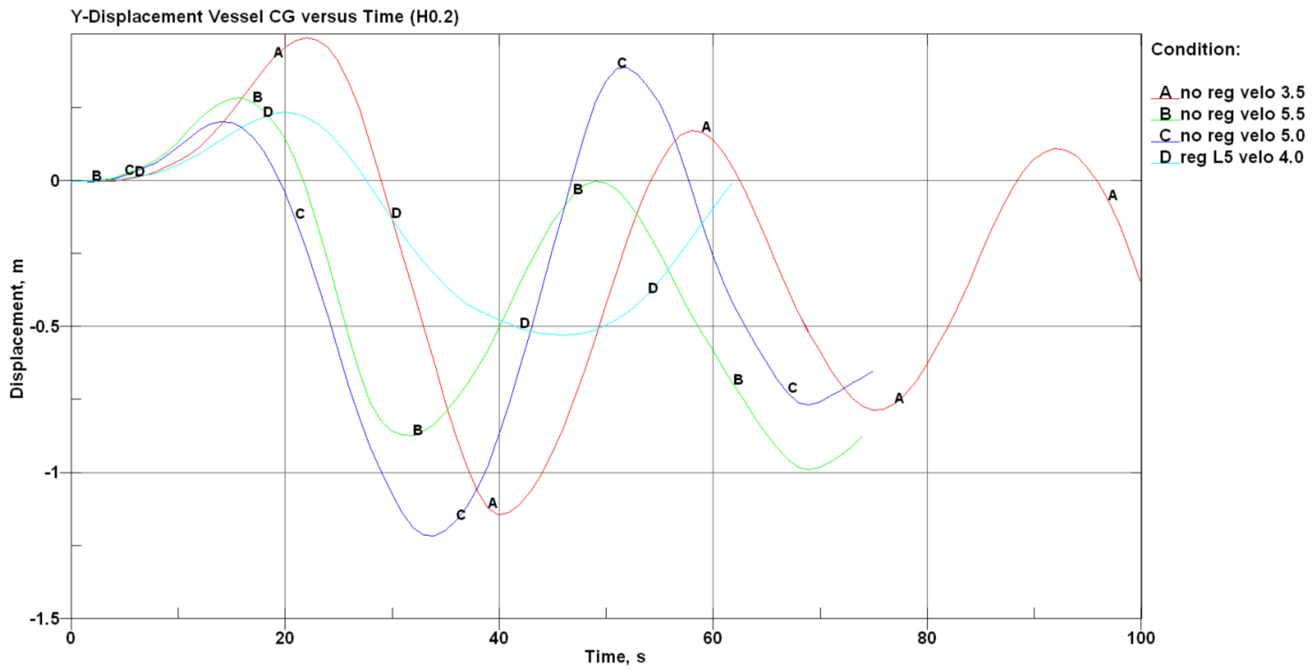
Processing of results of modeling showed that in thin ices (up to 0,2 m thick) at the chosen control laws of vessels their ice interference at a passing is negligible. It can be illustrated with the characteristic curves shown in fig. 2.

The analysis of characteristic curves of fig. 2 showed that in the specified ice conditions even at maximum ratings of a yaw angle and transverse displacement of vessels (curves of A and C, fig. 2) a width of band occupied by the vessel at a passing will not exceed size more than 1,33 of its own width.

In behavior of the passing motor ships in thick small ice cakes (from 0,5 m thick and more) danger of collision is also not expected even at the minimum initial beam distances (to 10 m) though quantitative characteristics of route stability get



a)



b)

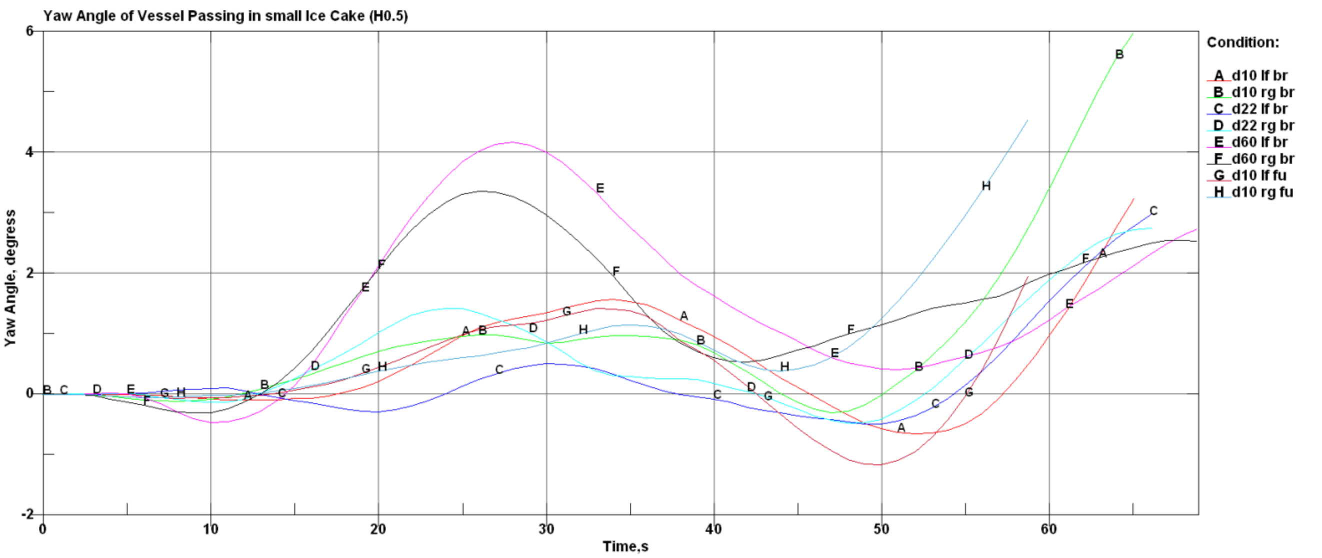
Figure 2 – Behavior of a yaw angle (a) and transverse displacement (b) of dry cargo ships type «Sormovsky» at a passing in ice cakes 0,2 m thick.

(A-C– «irregular» ice cake concentration of 9-10 balls at different speeds of a passing and the control law «without pullout»; D – «regular» ice cake concentration of 9-10 balls at the control law «without pullout»)

noticeably worse in comparison with similar parameters in thin ices (Fig. 3).

The numerical forecast shows that directly in the course of a passing the maximum yaw angle of vessels and their transverse displacements are in limits of 4,0 degrees and 4,0 m respectively (lines E, fig. 3). These parameters of the movement generate almost double width of a traffic lane (24,6 m) in relation to vessel width.

The probability of adverse reaction of the vessel at the movement in thick small ice cakes (especially at small beam distances) is high and consists in «high drift angle» of its



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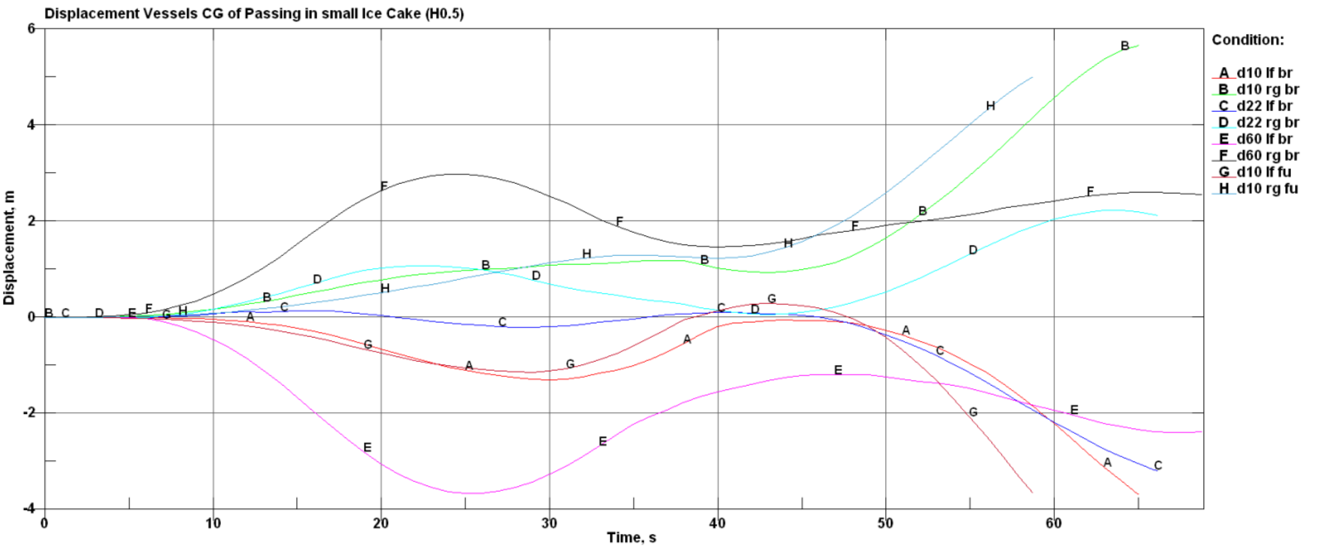


b)

Figure 3 – Behavior of a yaw angle (a) and transverse displacement (b) of dry cargo ships type «Sormovsky» at a passing in small ice cakes 0,5 m thick.

(A-H - options of the movement in small ice cakes concentration of 9-10 balls at different vessel speeds, passing distances and the control law «without pullout»)

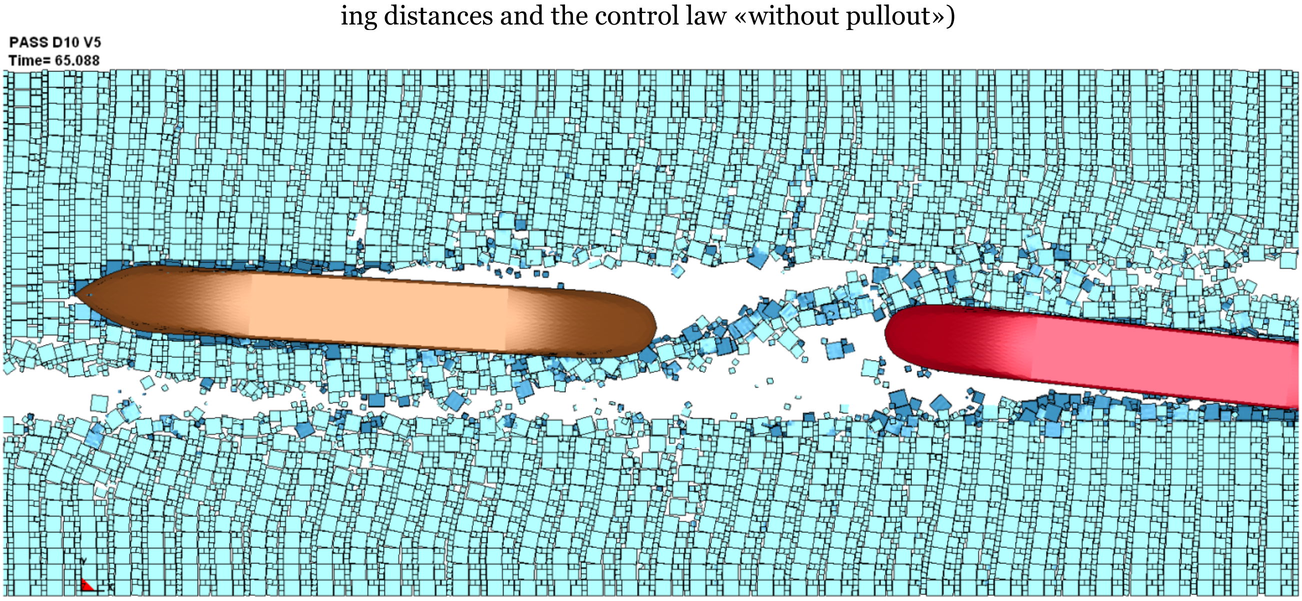
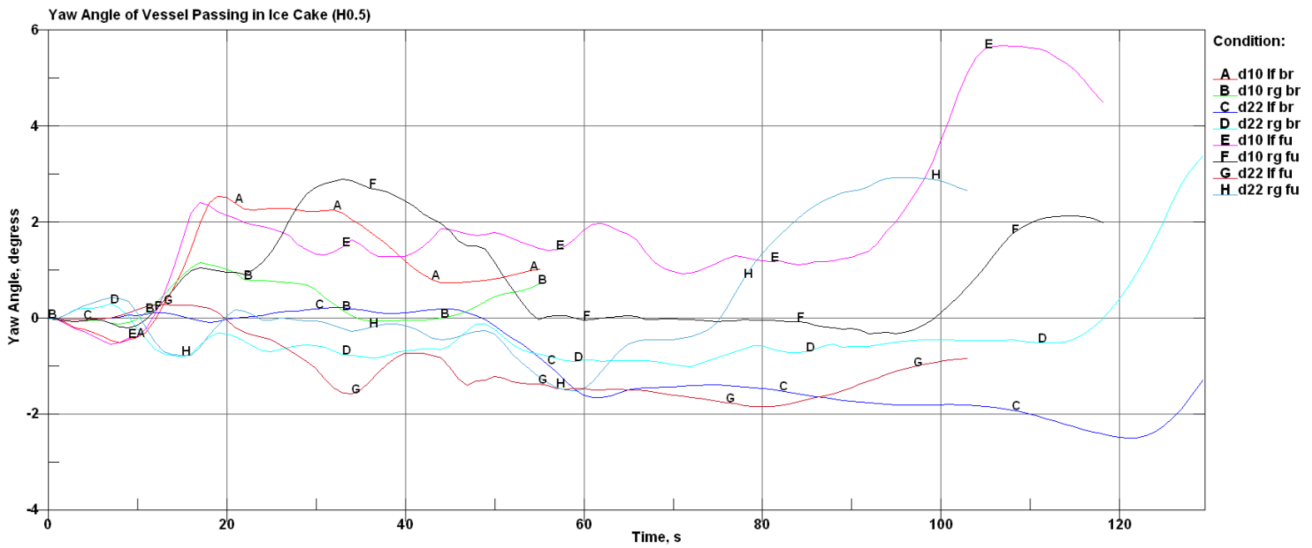
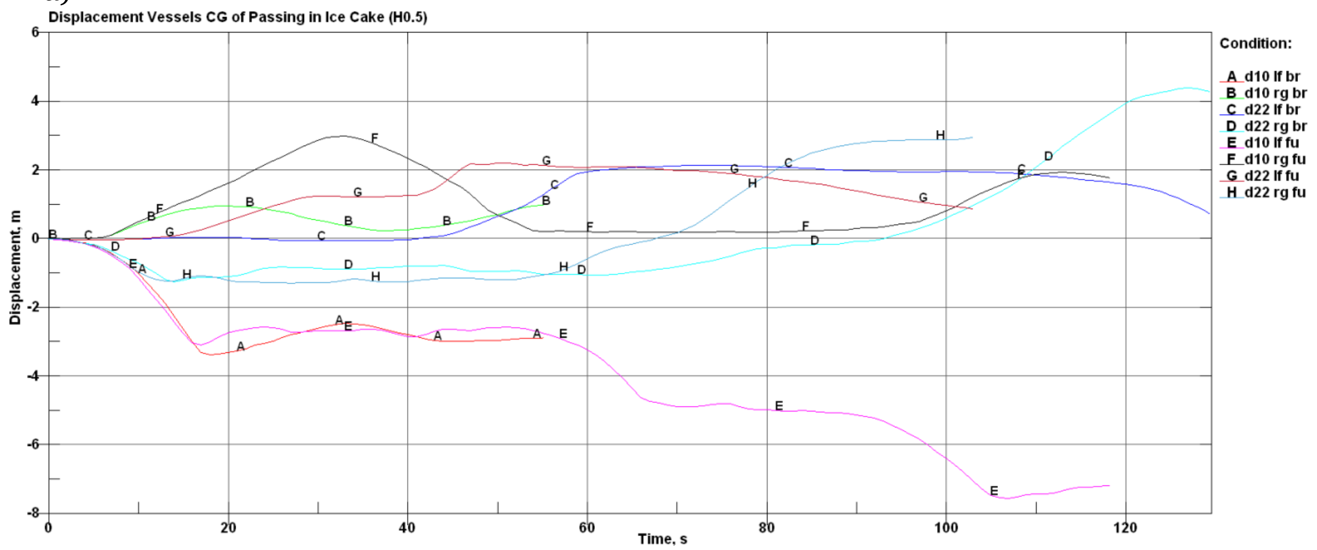


Figure 4 –«High drift angle» of a stern of vessels after a passing in thick small ice cakes.



a)



b)

Figure 5 –« Behavior of a yaw angle (a) and transverse displacement (b) of dry cargo ships type «Sormovsky» at passing in ice cakes 0,5 m thick.

(A-H - options of the movement in ice cakes concentration of 9-10 balls at different vessel speeds, passing distances and the control law «without pullout»)

stern towards an axis of the ice channel directly after a passing of motor ships (Fig. 4). It is possible to explain it with the fact that control according to the established law of vessels aim to return, whenever possible, rather to the leading (route) line with shift in the course of which passing is inevitable. Additionally, during this period the yaw angle and transverse displacement of vessels increase (lines B, fig. 3).

For thick ice cakes finite element modeling quite often predicts steady smooth drift of vessels in local zones of the smallest ice resistance, and also significant random «spikes» in characteristics of yaw (Fig. 5).

So, for example, in option E (Fig. 5) with an amplitude of transverse displacement of 7,5 m and a yaw angle of 5,5 degrees the width of a traffic lane of the vessel reaches 31,0 m. Therefore at small beam distances there is a probability of a slow impact of vessels at a passing (Fig. 6). It is recommended to keep a beam distance in such ices not less than 25,0-30,0 m.

On the constrained water areas covered with small ice cakes, in case of emergency the safe passing can be provided with performance of maneuver of mutual "evasion" of vessels. Numerical experiments did not find any contraindications of its

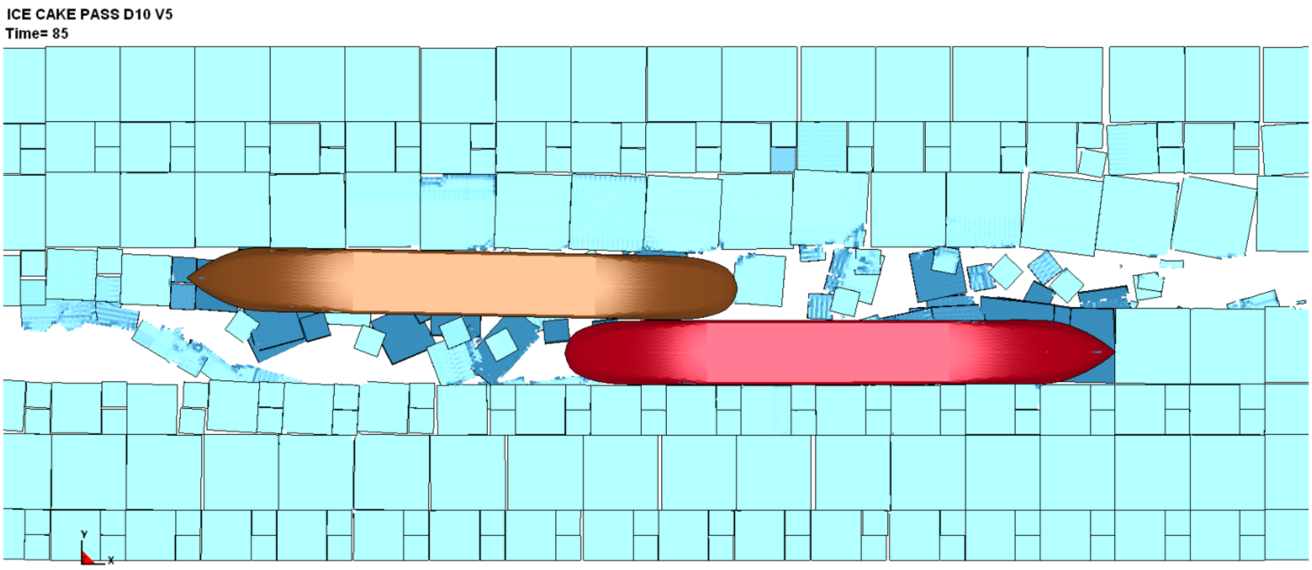


Figure 6 – A slow impact of vessels at a passing in thick ice cakes.

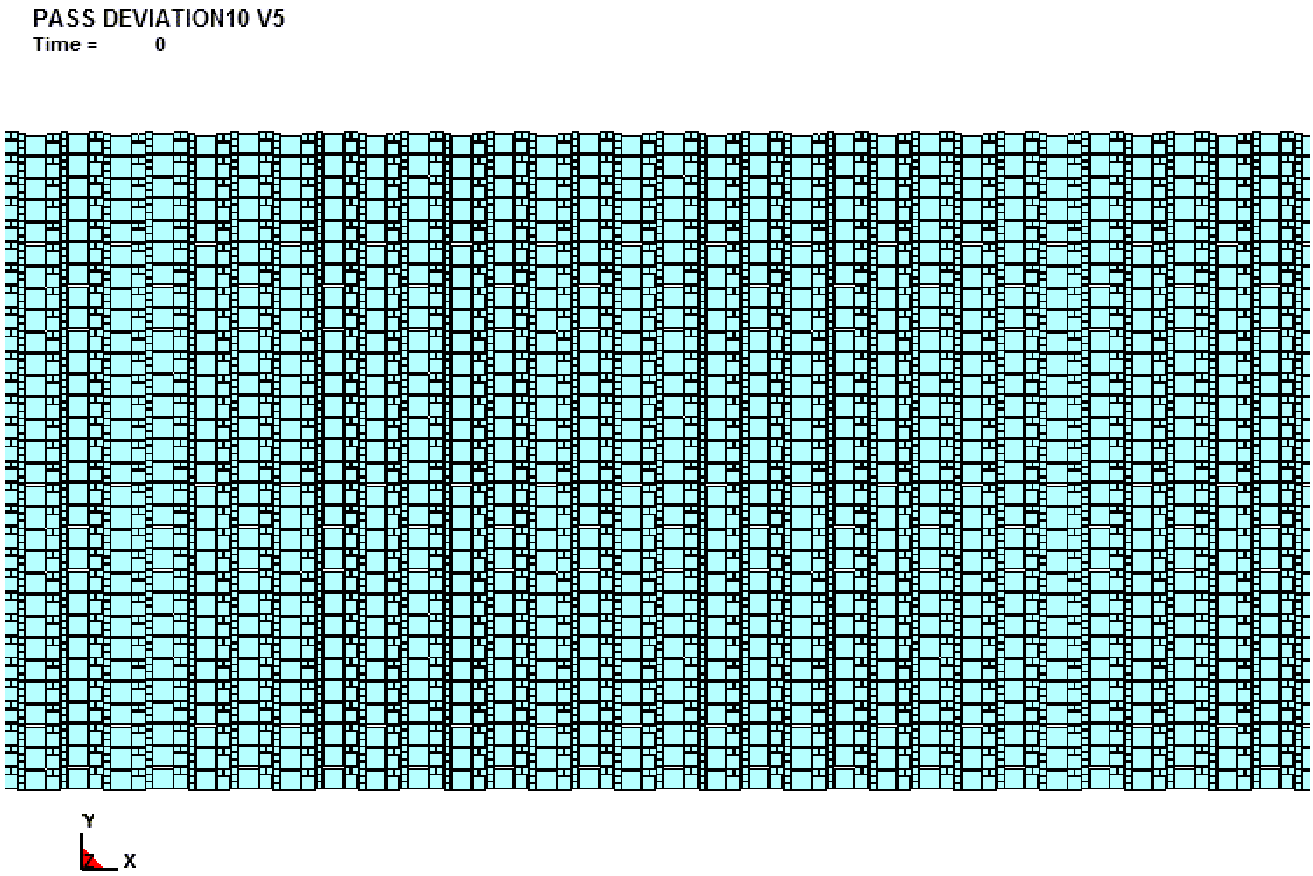


Figure 7 – Vessels passing in thick small ice cakes by performing of an «evasive» action.
(A control law of vessels –«with pullout»)

implementation in these conditions. It is illustrated in fig. 7 with animation of process of vessels passing in thick very compacted small ice cakes.

But in thick very compacted ice cakes the maneuver described above can hardly be recommended as safe. For these conditions the numerical model predicts obviously

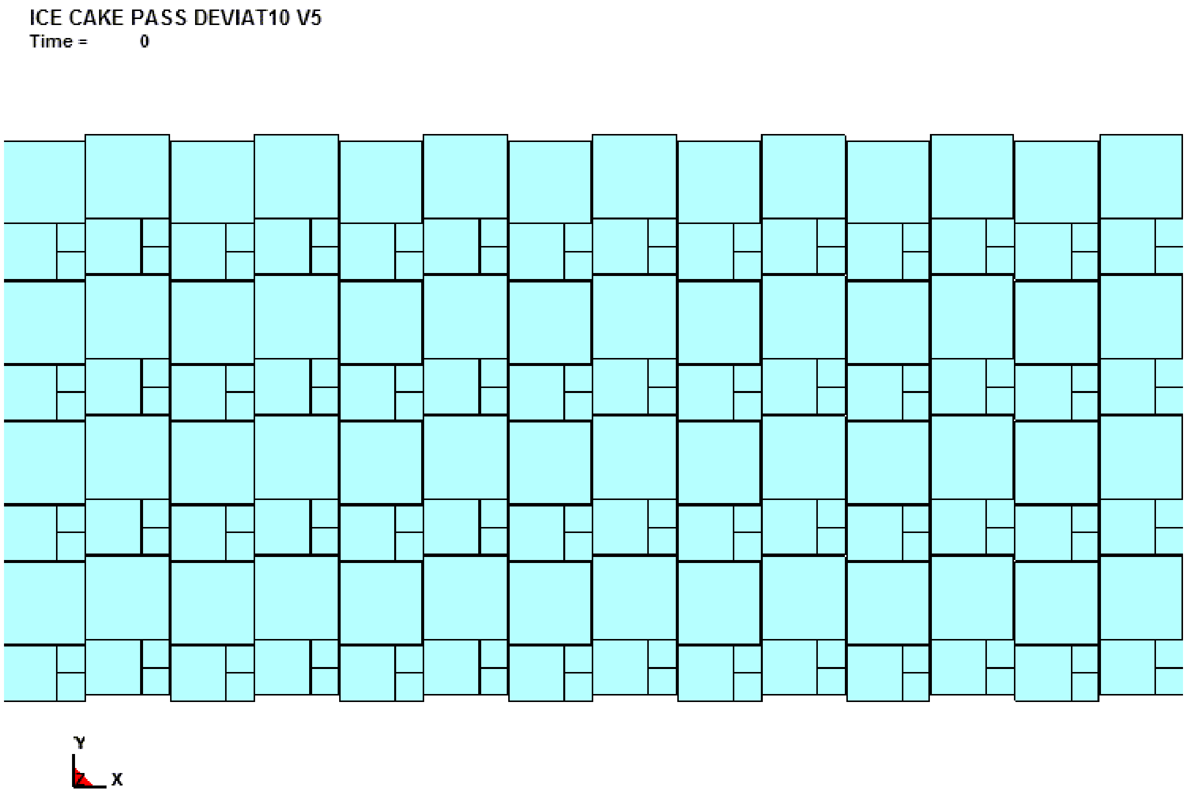


Figure 8 – Vessels passing in thick ice cakes by performing of an «evasive» action.
(A control law of vessels – «with pullout»)

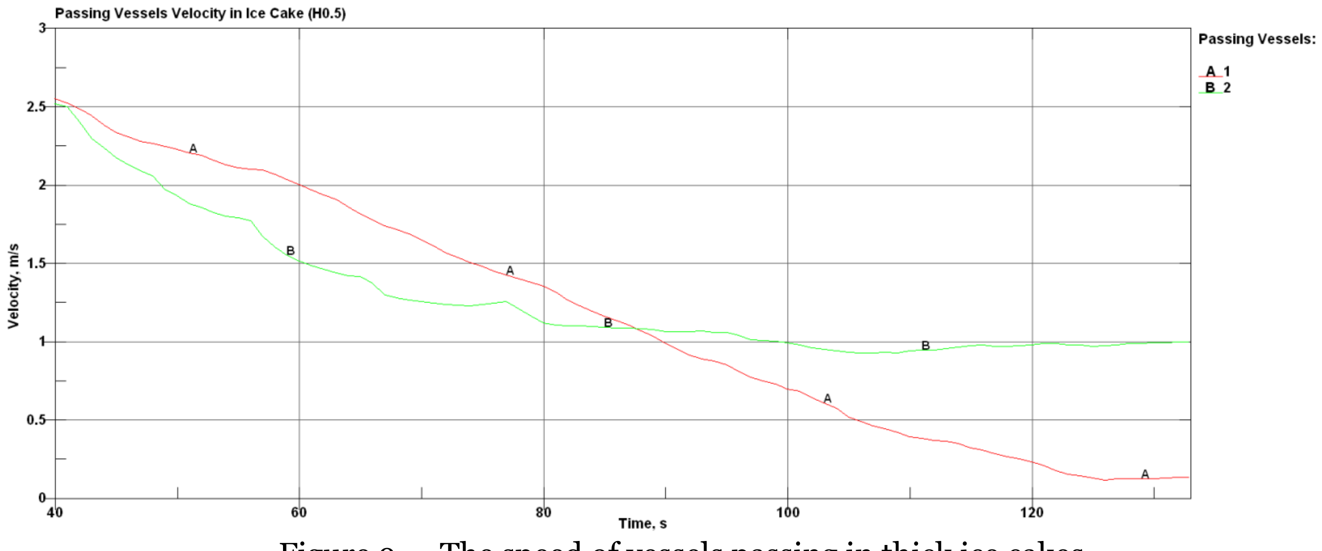


Figure 9 – The speed of vessels passing in thick ice cakes.

excessive rapprochement of vessels (time ≈ 60 c, fig. 8).

Initially bigger heterogeneity of ice environment from ice cakes, in comparison with small ice cakes, in addition is being aggravated by the maneuvering meeters can significantly affect their propulsion ability. In the example shown in fig. 8 and 9, the ratio in attainable speed of the movement of the same motor ships directly at a stage of a passing fluctuates within 1,25 - 5,0. It should be noted that the similar phenomena are short, but in the solution of short-term safety problems, at expert assessment of acceptable conditions of maneuvering their ignoring is incorrect.

4. Conclusion

1. The requirement for the numerical prediction of the consequences of vessels' joint maneuvering in ices at small distances is caused by inability of autonomous an-

alytical techniques to the description of dynamics of progress of similar processes.

2. Thin ices of different degree of size and thick small ice cakes are not dangerous to the dispersing vessels (including at the emergency passing an «evasive» action).

3. In thick ice cakes it is required to keep an interleading passing distance of transport ships not less than 30 m. The emergency maneuvering by «evasion» is not recommended.

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