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PRODUCTION SHIP RESISTANCE TO ICEBERG IMPACT STUDY

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ABSTRACT

The floating production unit (FPU) moored by a mooring system (MS) equipped by a rotating turret, seems to be the most acceptable in more than 300 m depth of the Barents Sea of extremely severe combinations of environmental conditions. All environmental loads are to be kept by the FPU MS - anchor station-keeping system; also flexible riser system safety should be provided. But it is well known, that floating moored platforms equipped by semi taut anchor lines poorly resist actions of drifting ice floes and, moreover, iceberg influence. Usually, an impact of an iceberg or a floating "stamukcha" (i.e. iceberg of salt ice) upon a floating facility is assumed to be irresistible. In such a case accident preventive measures should be undertaken. These measures imply: (1) relegation of the iceberg by tow vessels; (2) the FPU retreat by its own propulsive thrusters or tugs after emergency disconnection of the mooring/riser systems from the turret.

The disconnection procedures are complicated and dangerous and may be too late. Also a failure of the emergency disconnection system (EDS) may arise. In this case an iceberg impact is inevitable and its effects should be examined. As a the first approximation it may be proposed that the energy of iceberg impact may be compensated by absorption of its kinetic energy by the MS and FPU displacement with thrusters assistance. Also, the energy absorption by the FPU rotation around the turret due to eccentric contact impact should help an iceberg stop.

This paper demonstrates, that in the accident when the mooring lines disconnection has not been performed in a timely manner, the iceberg/stamucha with a limited weight (energy) may be stopped by the MS without essential damage of the facility.

KEY WORDS: FPU, EDS, ice force, iceberg, ice ridges (floating grounded hummock- "stamukcha"), iceberg drifting speed, iceberg energy, MS, time simulation.

OBJECTIVIES

Loads governing for the northern Barents Sea are wave loads and drifting ice along with iceberg impact. Usually it is assumed that contact of an iceberg on a floating moored platform is unacceptable. In case of iceberg threat the iceberg physical management- preventing iceberg from permeating into the near-field area or contacting with the FPU (G. Crocker et al, 1998. Mc

Kenna, 2007) is carried out. If there is no such possibility or in case of the unsuccessful operation for iceberg withdrawal, the urgent measures shall be taken in order to reduce risks as follows:

- activation the EDS (by disconnection of the mooring/ risers buoy from the lower part of the turret);
- FPU departure to the safe stand-by position;
- FPU repositioning (after the danger is over) and reconnection.

But even in case of successful disconnection, the reconnection is a difficult and dangerous operation and may take some months.

At the same time, it may be presumed that contact of a FPU with an iceberg of limited size and drifting speed may be conditionally safe for the facility and would require some possible emergency actions. Thus, the actual task is to determine limits for a mass and drifting speed of the iceberg, at which the above stated emergency prevention actions are not only salutary. Moreover, the MS may be designed in way to increase its ability to resist iceberg impact (energy).

The problem may be resolved by a rational design of the mooring lines combined of steel wires and long heavy chains. The horizontal displacement of the contact point and hence energy absorption may be increased by use of the rational ship heading control by the FPU thrusters.

ICEBERG THREAT IN THE EASTERN PART OF THE BARENTS SEA

Environmental conditions including iceberg statistics, were assumed for the eastern part of the Barents Sea based on information received from Russian Arctic&Antarctic Institute (AARI) (Zubakin et al, 2006 – the Book of papers of the AARI in Russian under prof. Zubakin's edition).

Based on long-term data isolines of iceberg recurrence (%) in the Barents are shown at Figure 1).

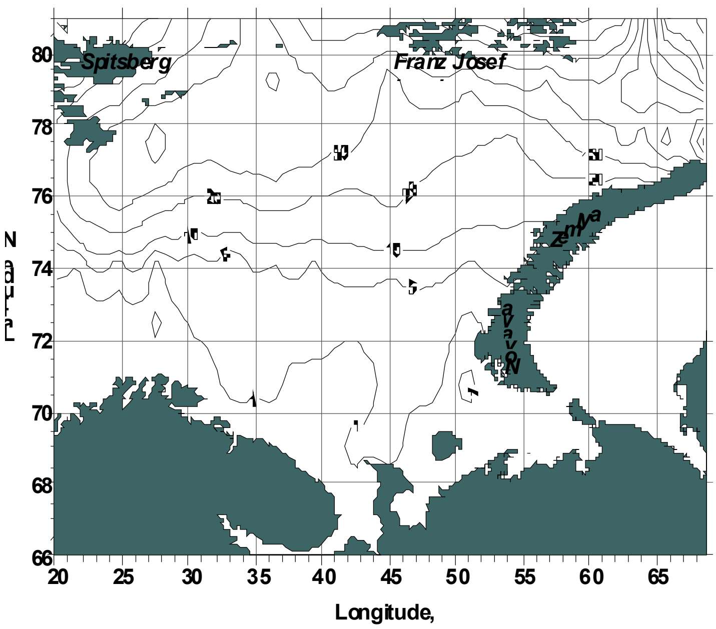

Figure 1. Isolines of iceberg recurrence (%) in the Barents Sea (as per data from 1928-1992, 2002-2005)

Statistical characteristics of drifting icebergs are given in Table 1.

Table 1. Statistical characteristics of drifting icebergs according to the expedition observation data.

Parameter	Average	Min	Max	Standard deviation
Length*, L (m)	140	15	526	107
Width*, B (m)	77	8	210	47
Draft, H (m)	50	5	137	28
Water-plane area, S (th. m^2)	12.2	0.3	74	15
Mass, M (kT)	927	2	8030	1382

As it can be seen the average iceberg mass in the Barents sea area does not exceed 1000 kT. In view of the comparatively low probability (3%) of iceberg appearance it could be assumed that impact of icebergs with mass more than 1000 kT on the FPU is unlikely to happen (once in 300 years) (Zubakin et al, 2006), also (Zubakin et al, 2005).

The statistical analysis of observation (Zubakin et al., 2006) has revealed that the average drifting speed of icebergs in the eastern part of the Barents Sea is 0.2 m/s and the maximum (rare) speed is 1.2 m/s. Figure 2 shows the curve for iceberg drifting speed module distribution law. As it may be seen from the curve the value for calculation of probable maximum iceberg energy may be assumed as 1 m/s.

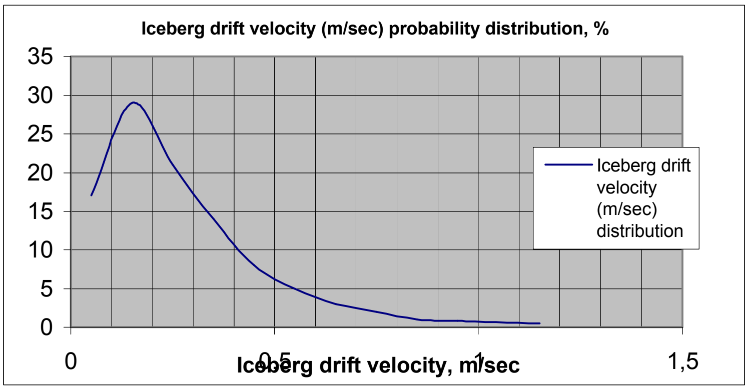

Fig. 2. Iceberg drift speed (m/sec) probability distribution, %

DESIGN PHILOSOPHY FOR MS of FPU

Resistance to ice/iceberg

Sufficient resistance of the proposed MS to ice/iceberg is ensured by the MS design that is aimed as follows:

— compensation of the static component of forces caused by action of ice floe including hummocks directly contacting the FPU hull;

— absorption of the kinetic energy of drifting iceberg by means of potential energy mooring lines coupled with the FPU rotating;

— reduction of the local dynamic load from ice floe or iceberg by slowed growth of contact force due to flexibility and damping properties of the MS.

Satisfactory operation of the MS designed for the mentioned purposes is maintained by:

- flexibility and damping properties of the mooring lines;
- appropriate turret position along the FPU hull;
- thrusters assistance that shall ensure the due FPU heading.

Ability of the proposed turret moored FPU to compensate for the global ice load under ice/iceberg action may be evaluated by means of a quasi-static analysis of energy-absorbing properties of the MS together with the hull and may be checked by computer simulation of dynamic iceberg-FPU interaction.

Iceberg Energy

The assessment of the platform ability to withstand iceberg impact is based on the energy balance method. The FPU MS coupled with the hull yaw shall have absorption capability (i.e. ability to accumulate potential energy) larger than kinetic energy of the drifting iceberg. The global dynamic ice load is obviously repulsed mainly by the MS.

Drifting iceberg kinetic energy may be calculated using the following formula:

$$\mathbf{E = 0.5\,(M + \lambda_{11})\,V^2} \qquad \textbf{(1)}$$

where E = iceberg kinetic energy, MN*m

M = iceberg mass, kT,

V = iceberg drifting speed, m/s,

$\lambda_{11} = k_{11}M$ – water added mass, entrained by iceberg, kT (average k_{11}= 0.7)

According to the data in Table 1 the energy calculation has been performed for probable iceberg with mass 500 kT, with drifting speed 0.4 m/s to 1,0 m/s with kinetic energy of 70 to 500 MN*m. These parameters correspond to the icebergs with parameters that are much higher than average values.

Energy Balance Calculation.

Iceberg kinetic energy is absorbed during displacement of the FPU due to the following two components:

a) accumulation of potential energy of the MS during tensioning of the mooring lines faced to the iceberg and energy loss due to the FPU inertia in shift&yawing (conservative forces);

b) energy loss due to viscous resistance of the FPU hull due to its horizontal speed and angular velocity in yawing (dissipative forces).

The FPU horizontal displacement and yaw under the iceberg transversal action were calculated applied in the three contact points along the FPU hull:

- "Bow"- 70 m from the turret to bow (see Fig.4),
- "Turret"- across the turret axis (see Fig.5),

- “Stern”- 140 m from the turret to stern (see Fig.6).

The following energy balance estimation is fulfilled in two stages

1^ST^ stage. The MS potential energy, depending on the force applied, is compared to the iceberg kinetic energy. The observed energy balance (without taking into account energy loss due to viscous resistance of the FPU hull) means that the MS is able to withstand the iceberg impact of the mentioned above energy.

2^nd^ stage. Computer time domain simulation of the FPU motion after contact with iceberg is carried out until the ship fully stops. In this case the total energy absorption by the platform is obtained both by non-linear resistance of the MS and by loss of energy due to viscous resistance of the FPU hull during its displacement. The iceberg stop while the FPU displacement and inclination are less, than the acceptable value (ref. to the item below), confirms that the MS and the ship are able to withstand the iceberg impact.

Design Limitations

The usage of flexible risers gives demanded tolerance for the FPU motions under environmental effects. Iceberg action is considered as abnormal load with reduced safety factor (SF).

The currently accepted limits of the FPU motions and line tensions during operation are specified as follows:

- Horizontal turret offset: Not to exceed 15% of the sea depth due to ice action; or 20 to 25% due to iceberg impact;

- Heel: Not to exceed 7 dg in level ice; 10 dg due to an iceberg impact;

- Safety factor in the anchor lines [SF=(line breaking force/actual line tension)]: Not less than 1,8 (ice action) or 1.05 (iceberg impact).

CALCULATIONS AND TIME SIMULATION

The FPU and the MS characteristics adopted for calculations

Sufficient resistance of the MS against iceberg impact is determined by configuration and geometry of the mooring lines with allowance for limited water depth. The FPU hull main features and MS parameters used in the calculations are shown in Table 2.

Table 2. FPU hull main features

Parameter	Value
FPU	
Length on WL, m	305
Width, m	48
Hull height, m	26
Draft (excluding turret), m	15
Draft over all, m	21
Displacement (volume), m^3	163000
Transversal metacentric height, m	2.8
Longitudional methacentric height, m	543
Turret location lever from FPU bow	-65.5

Parameter	Value
stem, m	
MS	
Number of lines	6x4
Line segments material	Wire rope / Chain
Diameter chain/rope, mm	152 /152
Length of segments (unloaded), m	600 / 600
Lineal weight in water, kN/m	1 / 4,5
Minimum breaking load, kN	21600/22300
Young's modulus, E, kN/mm^2	140 / 64,
Line pretension, kN	2000

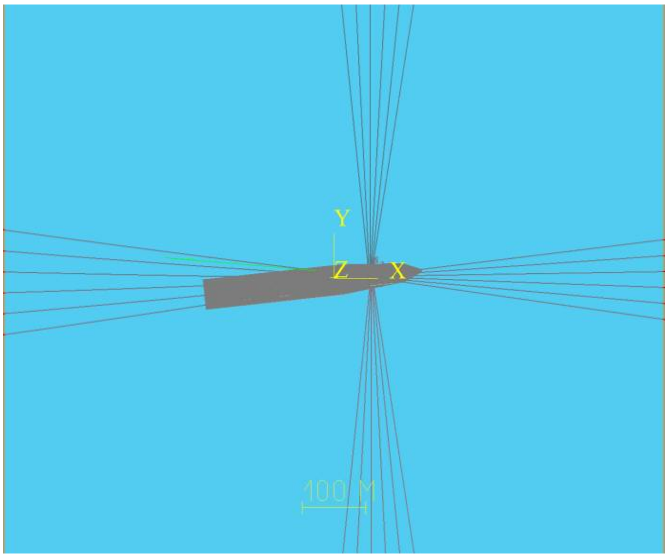

Figure 3. Plan view of the FPU moored by the disconnectable turret

FPU/iceberg interaction analysis

FPU/iceberg interaction dynamic analysis has been made using software "Anchored Structures" (AS) (Chernetsov et al, 2006). Iceberg kinetic energy up to 500 MN*m is considered. The FPU/iceberg interaction was performed by three contact points (bow, turret, stern) along the FPU hull that had assessed above. The time simulation has been fulfilled for iceberg of mass 500 kT and drifting speed 0.4 to1.0 m/sec, i.e. for the energy approximately 70 MN*m to 500 MN*m.

The snap-shots displaying collision of the iceberg and the FPU for three assessed points of the contact are shown in Figures 4 to 6.

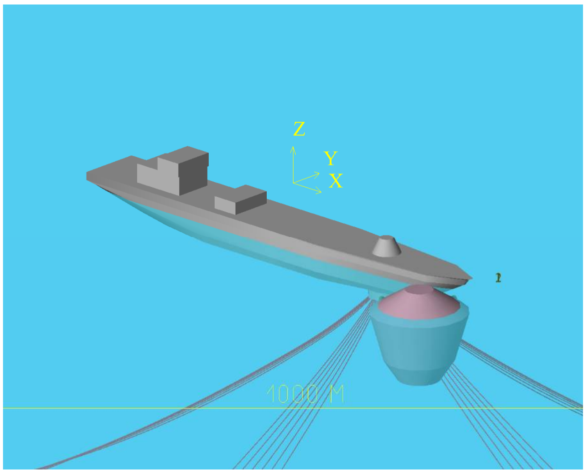

Figure 4. Snap-shot displaying collision of the iceberg and the FPU at the bow contact point

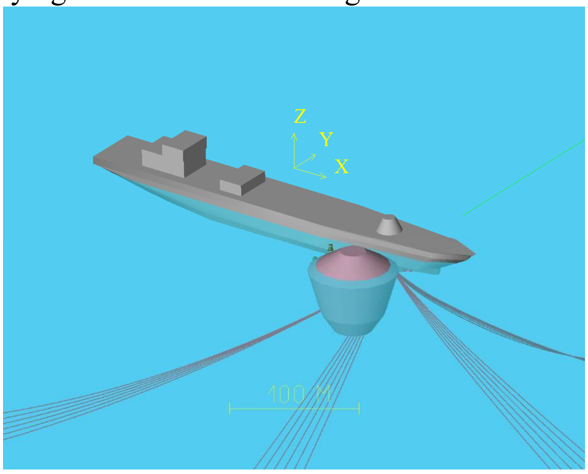

Figure 5. Snap-shot displaying collision of the iceberg and the FPU by the contact point “ turret”.

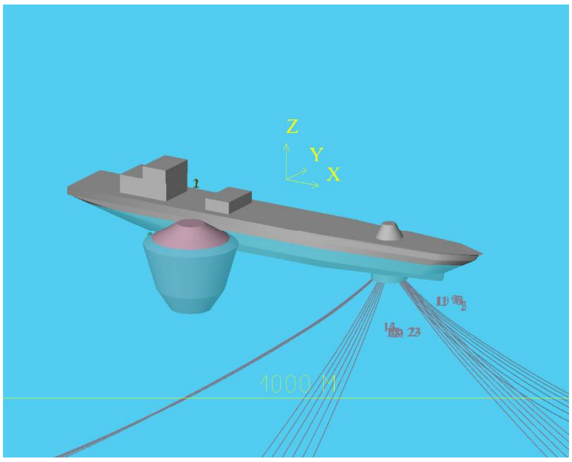

Figure 6. Snap-shot displaying collision of the iceberg and the FPU by the contact point ” stern”

In the process of simulation the collision by the bow or stern contact points has set up the FPU yaw around the turret and a longer path of the iceberg in contact with the FPU. Collision in the turret point set up mostly the FPU translational shift with the turret that leads to a shorter path of the iceberg with the FPU.

Therefore the last collision case allows absorbing less energy than the first two.

Results of calculations and time simulation

The results are presented at Figs 7 to 9, where contact force and absorbed iceberg energy versus horizontal shift of the contact points "bow", "turret" and "stern" are shown.

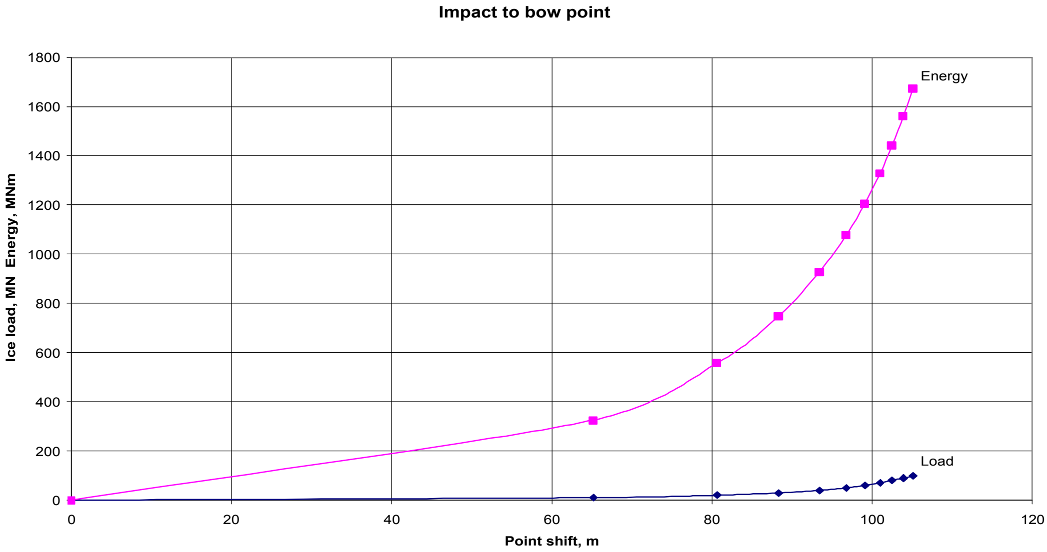

Figure 7. Iceberg/FPU hull collision by a contact point "bow". Contact force Fy and absorbed iceberg energy E versus horizontal shift of the contact point

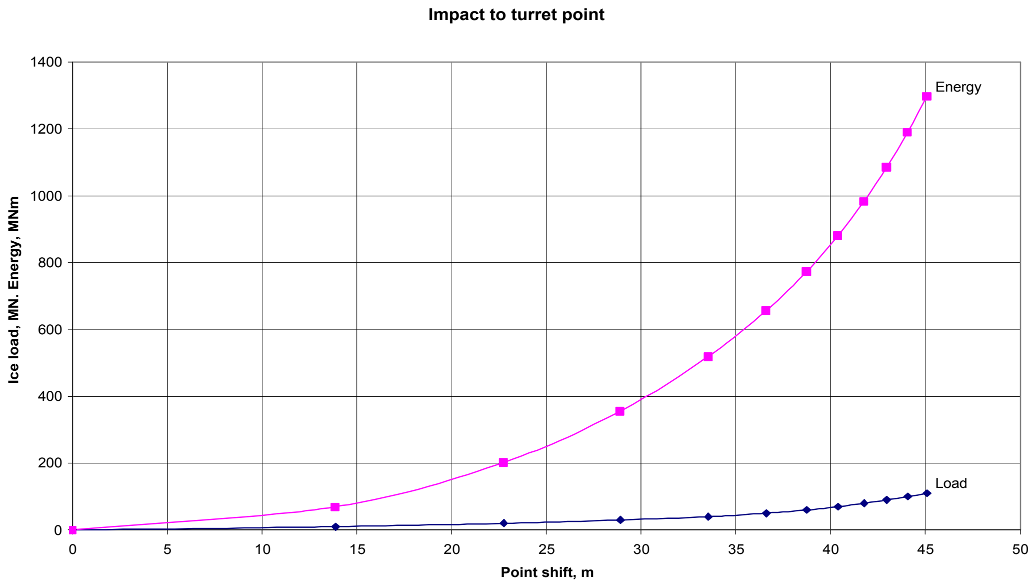

Figure 8. Iceberg/FPU hull collision by a contact point "turret". Contact force Fy and absorbed iceberg energy E versus horizontal shift of the contact point

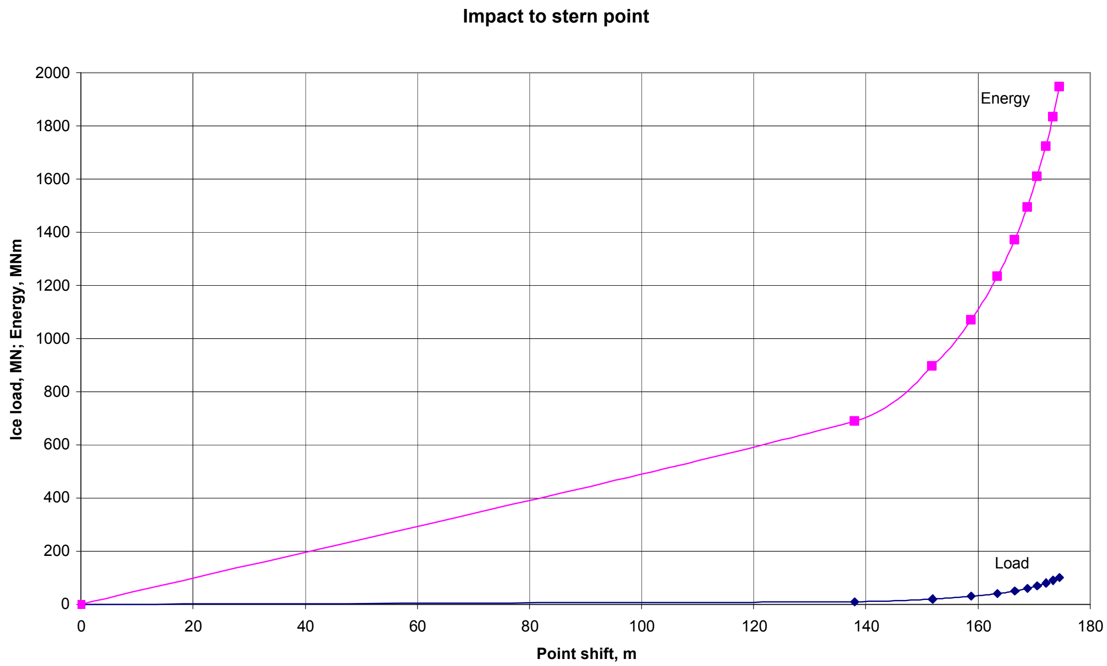

Figure 9. Iceberg/FPU hull collision by a contact point "stern". Contact force Fy and absorbed iceberg energy E versus horizontal shift of the contact point

The results indicated on the diagrams in Figures 6-9, are summarized in Table3.

Table 3 Results of the dynamic analysis results of the FPU/iceberg interaction.

Contact point	Max. ice force, MN	Horizontal displacement at the point of maximum absorbed energy (contact point iceberg/FPU hull), m	Max. absorbed energy, MH*м
Bow	100	105	1675
Turret	110	45	1300
Stern	100	174	1950

It may be concluded that in process of the FPU motion after the impact of iceberg to the remote contact points the absorbed energy is much more than in case of the impact to the "turret" point.

The simulation performed (considering water diffraction during interaction between the hull of the platform and the iceberg when approaching each other) has shown that speed of the iceberg is noticeably reduced when approaching the platform even before the contact with it, while the platform is slightly displaced. This hydrodynamic influence reduces mutual impact force in the contact.

CONCLUSIONS

1. The MS including seabed chains with the length of at least 600 m provide platform mooring with a displacement within allowable limits under impact of the iceberg with the energy up to

500 MN*m, that corresponds to the iceberg with the mass of 1 mln t with drifting speed of 0.4 - 0.7 m/s. Such icebergs are a rare phenomena in the Barents sea.

2. The results received give possibility (after performance of more detailed calculations and simulation) to make sure that in case of the inevitable iceberg impact (when the emergency disconnection of risers and mooring lines is turned out impossible or too late), the MS capability is in place. It is recommended to put the FPU bow part under iceberg strike in purpose to increase energy absorption. The required FPU heading should be provided by thrusters assistance but it is possible only in case of damaged ice (surrounding iceberg).

3. In case of the inevitable contact with a middle-sized iceberg or a large-sized hummock it is advisable to reduce tension of the mooring lines, which will increase energy absorption of the mooring system during the first phase of interaction.

4 Development of the MS which is able to resist against icebergs/ice ridges, needs of determination of requirements for:

a) the turret position along the FPU hull shall be optimal for the FPU operation kept by the MS,
b) mooring lines shall include seabed chains with the length of at least 600 m,
c) required FPU heading should be provided by thrusters assistance.

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REFERENCES

Crocker, G., Wright, B., Thistle, S., Bruneau, S., 1998, "Grand Banks Iceberg Management", *PERD/CHC Report 20-33,* Canada.

Mc Kenna, AMEC, 2007, *PERD/CHC Report 20-84,* Canada.

Zubakin, G.K., et al *(monograph in Russian)*, 2006, Ice Formations of Western Arctic Seas, AARI, Russia, pp 109-126.

Zubakin, G.K., Naumov, A.K., Skutina, E.A., 2005, Icebergs of Western Sector of Russian Arctic, *Proc. POAC-2005*, Potsdam, USA, Pp. 565-573.

Chernetsov, V. A., Karlinsky, S. L., 2006,"Ice-Resistant Spar-Type Platform for Middle Sea Depth" *Proc. ISOPE-2006,* San Francisco, USA, pp 716-722.