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ACCOUNT OF STRENGTH REQUIREMENTS AND DAMAGE CONTROL DURING REAL SALGAVE OPERATION OF RIVER-SEA TANKER

Показано, что целью аварийно-спасательных операций является спасение аварийных судов при последовательном выполнении приоритетных задач по спасению людей, предотвращению загрязнения окружающей среды и уменьшению ущерба собственности. Главное условие успеха таких операций – это возможность оперативно и квалифицированно прогнозировать состояния судна, оценивать остаточную прочность поврежденного корпуса, изменения посадки и остойчивости объекта спасения. Применение такого комплексного подхода к борьбе за живучесть судна показано на примере операции по спасению танкера «Григорий Бугров». Танкер получил пять пробоин днища по левому борту суммарной протяженностью 96 м, в результате чего 3000 т забортной воды влилось в корпус. Наличие 6138 т груза и 80 т запасов на борту затрудняло в значительной степени проведения спасательных мероприятий. Результат спасательной операции: команда не пострадала, удалось не допустить разлива груза, судно спасено.

Ключевые слова: *аварийно-спасательная операция, затопление, расчеты прочности, служба аварийной поддержки, борьба за живучесть.*

Показано, що метою аварійно-рятувальних операцій є порятунок аварійних суден при послідовному виконанні пріоритетних завдань з порятунку людей, запобігання забруднення навколишнього середовища й зменшення збитку власності. Головна умова успіху таких операцій – це можливість оперативно й кваліфіковано прогнозувати стан судна, оцінювати залишкову міцність ушкодженого корпуса, зміну посадки й остійності об'єкта порятунку. Застосування такого комплексного підходу до боротьби за живучість судна показано на прикладі операції з порятунку танкера «Григорій Бугров». Танкер одержав п'ять пробоїн днища по лівому борту сумарною довжиною 96 м, у результаті чого 3000 т забортної води влилося в корпус. Наявність 6138 т вантажу й 80 т запасів на борту ускладнило в значній мірі проведення рятувальних заходів. Результат рятувальної операції: команда не постраждала, вдалося не допустити розливу вантажу, судно врятовано.

Ключові слова: *аварійно-рятувальна операція, затоплення, розрахунки міцності, служба аварійної підтримки, боротьба за живучість.*

It is shown, that the purpose of salvage operations is rescue of damaged ships with sequential performance of priority tasks on rescue of people, prevention of environmental pollution, decreasing of property damage.

Capability of the operative and qualified prediction of the vessel's condition, estimation of damaged hull residual strength, change of the trim and stability of rescue object are the main conditions of success of such actions. The complex approach to survivability of the ship is considered on the example of the tanker «Grigoriy Bugrov» salvaging. The tanker received five damages of bottom shell at PS on the length of 96 m and 3000 t of outside water flooded into hull. The salvage operations were very hard because of presence of 6138 t of cargo and 80 t of stores onboard. Results of the salvage operation are as follows: the crew has no harms, cargo spill was avoided, and the ship is rescued.

Keyword: *salvage operation, flooding, strength calculations, Emergency Response Service, survivability.*

Problem statement. Purpose of the emergency salvage and underwater services (ESUS) is rescue of emergency vessels during consecutive carrying out priority tasks on people rescue, preventing environmental pollution and decreasing loss of property (vessel and cargo).

Certainly, a necessary condition for success rescue operations is presence of a specific personal experience and intuition, but sufficient condition is an opportunity to work out operative and qualified forecast of objects conditions, to estimate with help of computation (or sometimes by instrumental) methods the residual strength of the damaged hull as well as trim and stability alternations of the object of rescue.

Aim of this paper is demonstration (by the real examples) of realization of principles and approaches accepted for Emergency Response Service (ERS) in order to provide sufficient buoyancy, stability and strength of an emergency vessel in on-line regime with reference to actual hydrological and meteorological conditions.

Main text. Performance of these conditions is especially important at carrying out ESUS for vessels that transport dangerous cargoes onboard such as crude oil or petroleum products.

Beginning on 01.01.2007 due to Regulation 37.4 of MARPOL 73/78 Annex I, all oil tankers of 5000 tons deadweight or more shall have prompt access to shore ERS organization which is able to carry out operational damage stability and residual structural strength calculations.

Shore ERS center should have the software, allowing carrying out damage stability and residual structural strength calculations as well as estimation of oil spill after collisions, groundings, construction breakage, fires, explosions, etc. when emergency alternation of loading and/or hull load-carrying ability takes place.

According to the results of shore ERS center, calculations guidelines for the master are worked out. Guidelines include recommendations due to survivability fighting and decreasing of possible loss till composition of tug convoy for emergency towage.

Data base should be prepared to fulfil these ERS functions. Data base should be made for specific vessels, including early entered theoretical hulls and compartments, typical sections, strength building characteristics and typical loading conditions.

At every vessel's departure shipowner should inform ERS about vessel's actual loading which should be fixed at the data base.

Time of forwarding of calculation results and ERS recommendation towards the emergency vessel should not exceed 2 hours from the moment of ERS signal income.

ERS should be available round-the-clock without rest-days.

All the information should be duplicated.

For work providing ERS should have special communication channels intended only for a task in view.

The emergency actions scheme is given in the fig. 1. Actual survivability fighting at emergency vessel starts after making decision about saving vessel.

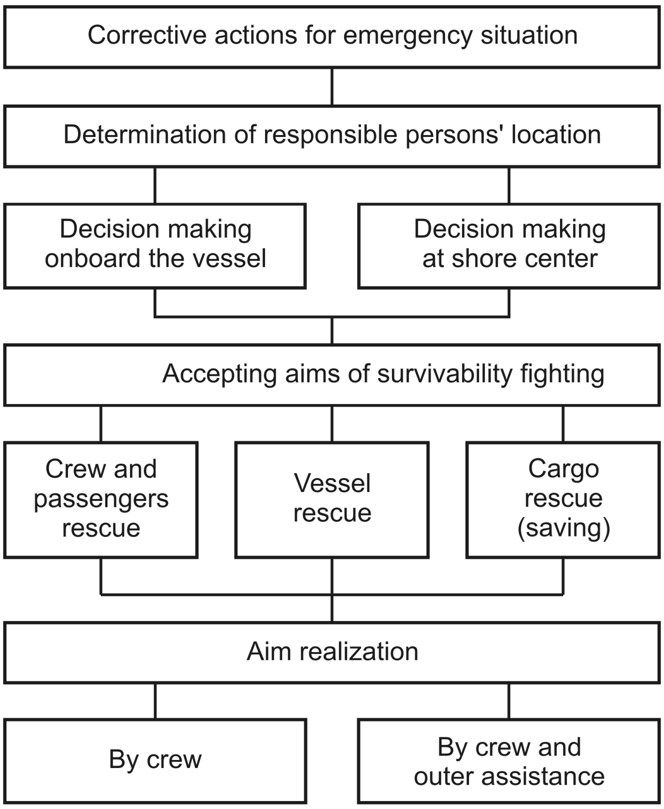

Fig. 1. Organization of crew and shore ERS center actions for an emergency situation correction

The problem consists in a high degree of uncertainty and transiency of emergency situation. In combination with responsibility for people's life, survivability of a vessel and safety of cargo this problem puts person accepting the decision in very rigid boundaries. Probably, this circumstance forced USA legi-slators by the first, and then and IMO ones to create shore support for the Master in order provide his actions in a critical situation.

Objective function of survivability fighting (i.e. vessel's saving) defines also requirements for providing safe moving the emergency vessel to the port after fulfilling operational measures. These requirements are based on meeting of the buoyancy, stability and strength criteria (see fig. 2).

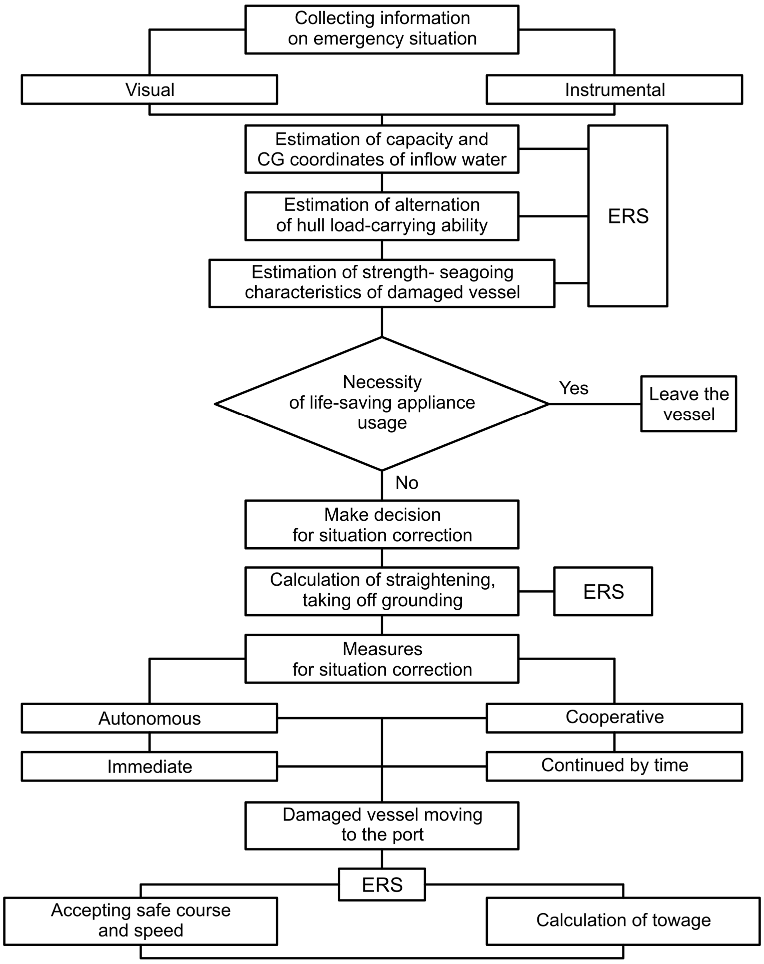

Fig. 2. Principal scheme of vessel's survivability fighting with help of Emergency Response Service

Survivability is formulated as vessel's hull ability to keep or restore in sufficient degree its operational characteristics after emergency alternation of loading and hull load-carrying ability and also after breakage of technical equipment. Besides unsinkability means survivability when hull's water-tightness is breached and some compartments are flooded.

Based on actual breakage's dimensions and loading alternation due to water incoming, one may states that significant decreasing of the general strength should be included into list of controlled emergency after-effects (see table 1).

In accordance with Egorov [1], while preparing recommendations one should take into consideration buoyancy restoration requirements (in a view of maximal fore and aft draughts criterion $d_F \le H$, $d_A \le H$), stability restoration requirements (in a view of minimal initial transverse metacentric height $h^{min} \le h$), heeling angle restriction requirements ($|\Theta| \le \Theta^{max}$), providing general strength after hull breakage requirements ($[M]_j^{min} \le M_j \le [M]_j^{max}$, $[N]_j^{min} \le N_j \le [N]_j^{max}$, $j = 1, 2, \ldots, k$) and also requirements due to restriction of compartments' capacity and constructions' local strength. Here d_F, d_A are fore and aft draughts; H is depth; h^{min} is minimal permissible initial transverse metacentric height; h is actual initial transverse metacentric height; Θ^{max} is maximal permissible heeling angle for concrete rescue operation; Θ is actual heeling angle; k is number of sections where bending moments and shear forces are controlled; M_j, N_j are bending moment and shear force at « j » controlled section; $[M]_j^{min}$, $[M]_j^{max}$, $[N]_j^{min}$, $[N]_j^{max}$ are permissible bending moments and shear forces at « j » section for sagging and hogging.

Table 1

Accident type influence on vessel's hull strength

Influence	Accident type				
	Collision to vessel or other floating object	Grounding (touching bottom)	Explosion	Fire	Leakage
Load-carrying ability (of breakage)	+	+	+	Thermal deformations of construction	-
Loading					
Outboard water	+	+	+	-	+
Cargo's leakage	+	+	+	-	+
Situation correction (straightening, taking off groun-	+	+	+	+	+

ding, firefighting)					

In accordance with [2], still water permissible values $[M]_j$ and $[N]_j$ are defined in a form $[M_{SW}(x_i)] = \frac{0.8}{K_\Delta K_{BI} K_\theta} \cdot \sigma_T^H W_{min}^0 - M_W$, where K_Δ is applied to normal tensions rising due to missing part of longitudinal members and due to oblique bend; K_{BI} is coefficient of tensions rising (due to bi-moment) at open-type high damaged sections; K_θ is coefficient of normal tensions rising at static heeling; M_W is maximal value of bending moment for short trip (towage) route to the nearest shelter port; W_{min} is minimal hull's section modulus after damage; σ_T^H is normative yield limit od hull's steel.

Generally when equivalent girder element with cross-sectional area ΔF, coordinates Y_D, Z_D and own inertia moments i_Y, i_Z failure it is possible to use the following definition scheme for the changed geometric characteristics of cross section (its initial characteristics are I_Y and I_Z for inertia moments and F_0 for cross-sectional area):

1. Let's assume main centroidal axes (see fig. 3) for undamaged hull as comparison axes. Inertia moments around comparison axes are $I_Y^{/} = I_Y - \Delta F \cdot Z_D^2 - i_Y$, $I_Z^{/} = I_Z - \Delta F \cdot Z_D^2 - i_Z$, $I_{YZ}^{/} = -\Delta F \cdot Z_D \cdot Y_D$.

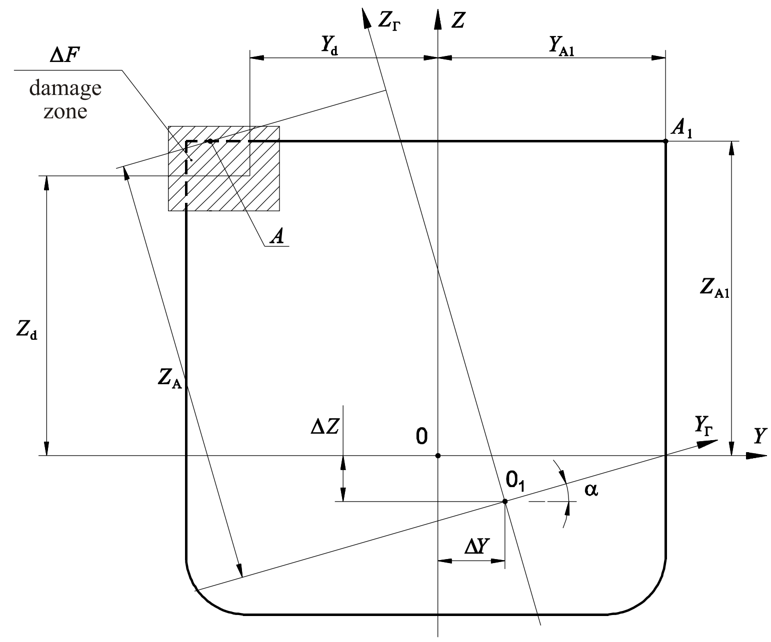

Fig. 3. Damage vessel transverse section scheme

Note. CG coordinates of missing element and most distant point ($Y_A^/$, $Z_A^/$) are given due to comparison axes.

2. Section CG new position

$$\Delta Z = -Z_D \Delta F/(F_0 - \Delta F),\ \Delta Y = -Y_D \Delta F/(F_0 - \Delta F).$$

3. Inertia moments around centroidal axes that are parallel to comparison axes can be defined as follows (we assume that missing element has negligible own cross-sectional inertia moments $i_Y \approx 0$ and $i_Z \approx 0$)

$$I_{\text{Y}}^{//} = I_{\text{Y}}^{/} - \Delta Z^2 \left(F_0 - \Delta F\right) = I_{\text{Y}} - \Delta F Z_{\text{D}}^2 \left(1 + \frac{\Delta F}{F - \Delta F_0}\right) = I_{\text{Y}} - \Delta F m Z_{\text{D}}^2\ ;$$

$$I_{\text{Z}}^{//} = I_{\text{Y}} - \Delta F m Y_{\text{D}}^2\ ;$$

$$I_{\text{YZ}}^{//} = -\Delta F m Z_{\text{D}} Y_{\text{D}}\ ,$$

where $m = 1 + \dfrac{\Delta F}{F_0 - \Delta F} = \dfrac{F_0}{F_0 - \Delta F} = \dfrac{1}{1 - \Delta F/F_0}$.

4. Angle of main axes $0Y_{\text{Г}}$ и $0Z_{\text{Г}}$ tilting to centroidal axes is

$$tg2\alpha = \frac{2I_{YZ}^{//}}{I_Y^{//} - I_Z^{//}} = \frac{2\Delta F m Z_D Y_D}{(I_Y - I_Z) - \Delta F m (Z_D^2 - Y_D^2)}\ .$$

5. Main inertia moments are

$$I_{\text{YГ}} = I_Y^{//} cos^2\alpha + I_Z^{//} sin^2\alpha - I_{YZ}^{//} sin 2\alpha =$$
$$= \left(I_Y cos^2\alpha + I_Z sin 2\alpha\right) - Fm\left(Z_D^2 cos^2\alpha + Y_D^2 sin^2\alpha - Z_D Y_D sin 2\alpha\right).$$
$$I_{ZГ} = I_Z^{//} cos^2\alpha + I_Y^{//} sin^2\alpha - I_{YZ}^{//} sin 2\alpha =$$
$$= \left(I_Z cos^2\alpha + I_Y sin 2\alpha\right) - Fm\left(Y_D^2 cos^2\alpha + Z_D^2 sin^2\alpha - Z_D Y_D sin 2\alpha\right).$$

6. Angle γ of neutral axis tilting to main centroidal horizontal axis is

$$tg\gamma = -\left(I_{YГ}/I_{ZГ}\right)tg\alpha\ .$$

7. Coordinates of most distant from centroidal axis point A due to main centroidal axes are

$$Z_A = cos\,\alpha\left(Z_A^/ - Y_A^/ tg\alpha - (m-1)(Z_D - Y_D tg\alpha)\right),$$
$$Y_A = cos\,\alpha\left(Y_A^/ - Z_A^/ tg\alpha - (m-1)(Y_D - Z_D tg\alpha)\right).$$

For definition of such point it is necessary to look through corner points of undamaged section with initial coordinates $Y = \pm B/2$ and $Z = -KH$, or $Z = (1-K)H$, where B and H means breadth and depth of vessel's hull accordingly.

For hardly damaged hulls one or two corner points change their coordinates due to comparison axes (because of alternation of cross-sectional geometry).

Maximal normal stress acting as a result of such damage is

$$\sigma_{max} = M(x)\left(\frac{Z_A}{I_{YГ}}cos\,\alpha + \frac{Y_A}{I_{ZГ}}sin\,\alpha\right) = M(x)\frac{Z_A}{I_{YГ}}\beta = K_\Delta\sigma_0,$$

and it exceed the initial stress σ_0 in K_Δ times.

Thus $K_\Delta = \frac{\sigma_{max}}{\sigma_0} = \frac{Z_A}{Z_{A1}^{/}}\frac{I_Y}{I_{YГ}}\beta$, where $\beta = cos\,\alpha\left(1 + \frac{Y_A}{Z_A}\frac{I_{YГ}}{I_{ZГ}}tg\alpha\right)$.

The most important part of survivability fighting for floating vessel is straightening (see fig. 4), which usually means as taking operational measures due to heeling and trim eliminating after accident.

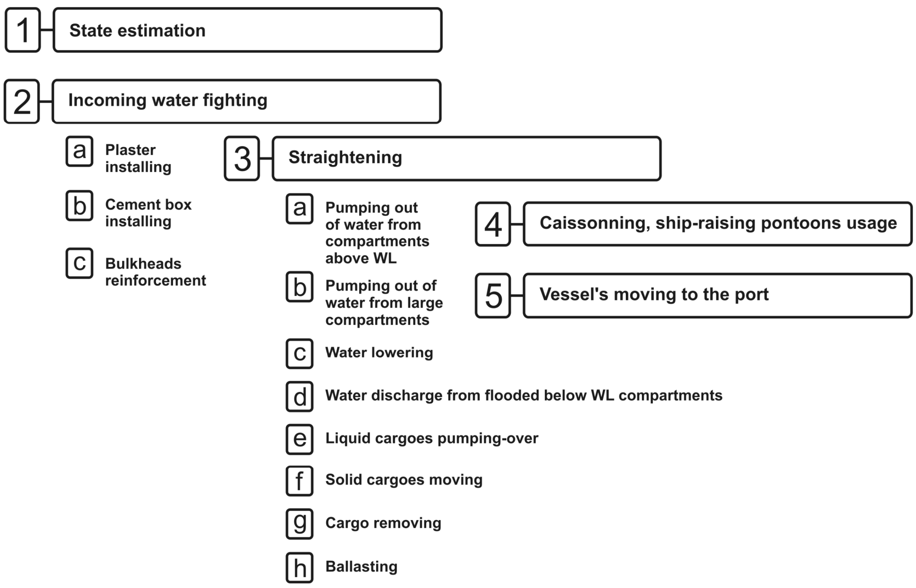

Fig. 4. Principal scheme of survivability fighting for grounding, collisions and water-tightness breaching

As an Example of successful actions of a shore emergency response service is work of operative ERS group of Marine Engineering Bureau (MEB) on computation forecast of trim, stability and strength during rescue operation of tanker «Grigoriy Bugrov».

Motor vessel «Grigoriy Bugrov» («Volgoneft» type tanker project 1577) has dimensions L x B x H = 128.6 x 16.5 x 5.5 m; she is steel, single-deck, double-screw river-sea RS class tanker, with double bottom and double sides, with forecastle and poop, with trunk, with ER and pump rooms and deck-house located aft, with 8 cargo tanks.

Main watertight bulkheads are located at 27, 34, 61, 79, 97(133), 151, 169 and 196 frames.

Frame space is 400 mm at the fore end, 600 mm at the aft end and 660 mm in the cargo area.

During renovation part of vessel's hull in the region of fr. 34-169 was produced anew with alternated geometry in accordance with MARPOL requirements (double bottom height of 1100 mm in CL and of 1650 mm at inner bottom). Also 1500 mm height trunk was constructed. Section modulus of the middle part of the newly built hull had 16 % reserve comparing with RS class requirements. Hull elements' thickness in the middle part of the hull was increased in order to meet class requirements (see fig. 5).

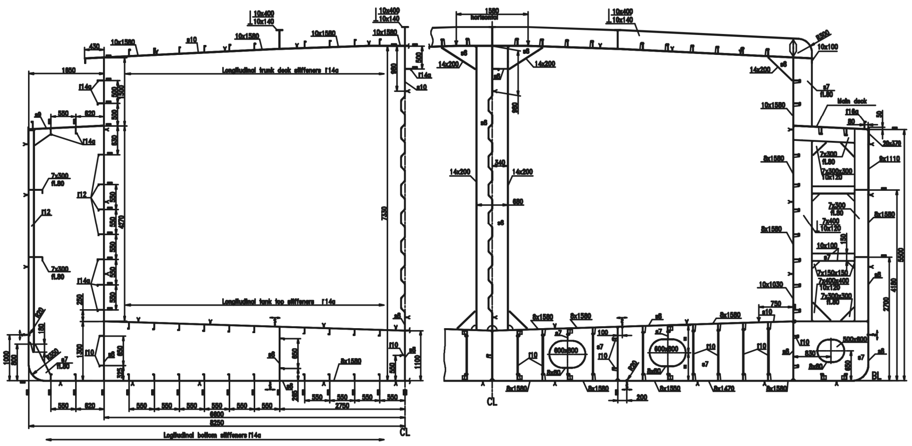

Fig. 5. Midship section of tanker «Grigoriy Bugrov»

Unlike usual «Volgoneft» type tanker «Grigoriy Bugrov» had got 4 groups (not 2 ones) of ballast tanks in the middle part of the hull. This moment facilitates vessel's position during accident.

On October 13, 2011 at 14:32 tanker having onboard 6138 tons of cargo (mazut) and stores (44 tons of diesel fuel, 1.5 tons of lub. oil, 5 tons of oily water and 30 tons of fresh water) has impacted at unknown underwater object.

After collision in short time engine room has been flooded, vessel has stopped, electrical plant has failed. Vessel's list became of 27 degrees and simultaneously there was huge trim aft.

In a result the tanker grounded by stern at the point with coordinates 44º 28'08" N, 48º 12'06" E. (northern part of Caspian Sea, 75 miles from Volga mouth and 94 miles from port of Makhachkala). The crew in amount of 11 people has been rescued by dry cargo vessel «Amur 2515».

Cargo spillage was avoided, because tanker «Grigory Bugrov» in 2005 was significantly re-equipped under project of the MEB with full replacement of a cargo zone and hull renovation for 2SS level (hull strength corresponds to 10-years old vessel). After that re-equipment vessel fully complies with requirements of MARPOL Convention.

From 18:00 of October 13, ERS of MEB started providing tanker salvage.

Numerical model of the accident situation from the trim, stability and strength was worked out till 19:00 on 13.10.11. After numerical model was improved due to new information and subsequent prompt recommendations for the emergency branch were made.

At the beginning about 2800 tons of water flowed into vessel (about 1600 toms into ER, about 1200 tons into PS ballast tanks 25, 11, 13). Later on water flowed into compartments of poop and superstructure at PS, so list increased up to 30 º and total water amount was about 3000 tons.

Due to non-symmetrical flooding ship position was characterized by huge list (30 º PS) and huge trim (4.5 m aft). Fore part of the vessel was afloat due to buoyancy reserve of the fore compartments and empty spaces within cargo tanks.

Stresses in the hull in such condition (without wave component) were within acceptable bounds. But situation was able to change in a cardinal way in case of storm.

The most dangerous zone was in the region of the pump room (in front of superstructure); still water bending sagging moment here was of about 59500 kNm. Bottom was tight, but it wasn't dangerous when moment was of such small value. But then hogging increased due to cargo discharge from aft tanks, so danger of hull breakage appear because this region is a weak place for «Volgoneft» vessels type.

Note. Vessel's cargo zone was newly built, but aft end of the vessel (beginning from pump room) was kept from the initial hull with transverse framing system and small thickness of hull elements.

Damage stability calculations showed real problems with dynamic stability (there was ability of vessel's overturning from waves impact).

As a result first priority tasks were defined, as follows: decrease aft draught (making vessel afloat) and list decreasing with simultaneously strength control at the area of pump room.

Main aim was to get vessel's conditions with maximal draught less than 4.2-4.3 m (for providing ability of tanker's towage to Astrakhan.

Action variants were analysed, as follows:

1. Hermetic sealing flooded compartments and their discharging:

- poop compartments (because of big free water surface;

- ER and steering gear room compartments (because of big aft trim, huge stability and buoyancy loss and, as main, for significant hogging moment that was dangerous for hull in the area of the pump room);
- ballast tanks (11, 13 and 25) because of list.

2. Cargo discharging.
3. Combination of above two methods.

Prompt calculations were effected. They showed that it was necessary to work out variants 1 and 2 simultaneously.

After discharging cargo tank 7PS (846 tons of cargo) hogging moment in the dangerous zone increased up to 85900 kNm. It was permissible value but noticeable. Moreover there was bottom damage with unknowable sizes (at the moment of calculations work out).

After discharging tank 7 PS it was necessary to discharge tank 5 PS in order to decrease list. Thus hogging moment decreased down to 42000 kNm; list decreased significantly and dynamic stability became better.

In a result of different rescue variants modelling, ERS of Marine Engineering Bureau issued the following recommendations:

1. To discharge cargo tank 7 PS for maximal level;
2. To provide discharging cargo tank 5 PS (it was noted that during this stage list to StB should appear, and after such moment discharging tanks 5 PS and 8 StB should be done simultaneously till reaching necessary draughts and list eliminating);
3. To press water out of ballast tanks 11 and 13, then 25 and 9; then out from ballast tank 12 (later water in ballast tank 12 was discovered; evidently this tank was flooded after accident as a result of air pipes damage during storm on October, 19-21);
4. To provide hermetic sealing and discharge poop, steering gear room and ER compartments.

It was foreseen to unload cargo from tanks 6 and 8 (symmetrical ones for tanks 5 and 7) in order to eliminate list.

When stern started moving up further water discharging from ER was accomplished with cargo transfer from tanks 3 and 4 to the tanks 5 and 6. Aim of this transferring was avoiding fore trim.

During operation recommendations were corrected in connection with getting actual data on damaged compartments (e.g. ballast tank 12 flooding and breach at the forecastle) and on actual capacity equipment (the pump temporarily placed in a cargo tank 5 had the essentially greater capacity than the one in a cargo tank 7), etc.

Actual dimensions of breakages were detected later when vessel started to float up. Early vessel has «laid» on these breaches.

On October 21, at about 22:00 first breach was discovered. It was placed through the bottom shell in the shoulder region of the ballast tank 9. It dimensions was as follows: 5.5 m length and up to 35 cm width.

Further five breaches have been detected and sealed, as follows: in area of forepeak PS, in area of a ballast tank 9, between ballast tanks 25 and 13, between ballast tanks 13 and 11, and also on the bottom of ER. Lengths of breaches were from 4 to 8 m with breadth up to 35 cm.

In a result, salvors provided vessel afloat (in the morning on October, 22), heel and significant trim were avoided, intact stability was recovered also the hull strength was not damaged.

Till 19:45 of 23th of October all main survivability actions including masut discharge were completed. Amount 4405 cub.m. of cargo was discharged.

Thus, the tanker has suffered from bottom damages PS on a length of about 96 m (72 % from vessel's overall length) and about of 3000 tons of water flowed into vessel (28 % of summer freeboard displacement). Taking into account, that there was onboard also 6138 tons of a cargo and about 80 tons of stores, it is necessary to recognize, that vessel's condition was extremely dangerous and operation with such object was very hard (as they say, «on the verge of possible»).

On October, 20 MEB developed and approved at the Astrakhan RS branch Grounding of tanker towage (2 variants, conveyance to the port of Astrakhan or Makhachkala). Document was developed due to order of Branch of eliminating accident fall-out. Conclusion of this document included, as follows:

1. Wind-wave conditions in the region allow one-time trip in the form of towage by wire without crew with permissible 3% probability wave height of 2.5 m;

2. Damage trim and stability of the vessel during one-time trip meet RS Rules requirements for all inspected cases;

3. During one-time trip vessel's strength with account of damages meet RS Rules requirements with restriction of 3 % probability wave height of 3.5 m;

4. For one-time trip restriction for permissible 3 % probability wave height of 2.5 m is set. This will provide additional strength reserve.

Such one-time trip was successfully carried out beginning at 24.10.11 at 03:0 and completing at 25.10.11 at 17:45.

On 25.10.2011 convoy with the emergency vessel arrived to the port of Astrakhan. At 17:45 «Grigoriy Bugrov» was moored at the berth No.3 that belongs to the special enterprise CJSE «ECO+».

Conclusions. The considered example evidently shows principles and approaches of a shore Emergency Response Service in order to provide survivability fighting and computation forecast of trim, stability and strength in on-line regime, with participation of ERS experts which have computation means and are able to use them.

Result of rescue operation is as follows: crew didn't suffer, cargo spill was avoided, vessel «Grigoriy Bugrov» was rescued.

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