COMPREHENSIVE APPROACH TO SAFETY OF MARITIME CONTAINER TRANSPORTATION

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ABSTRACT

The whole complex of factors of risk and safety problems in terms of maritime container transportation is accompanied in the article with scientific analysis, which aims to find the most rational organizational and technical solutions. This task is performed in a constructive way, consistently and objectively, using algorithms of calculation and methodological tools that promise to secure control over safety of containers in a terminal and on a ship in the process of goods movement across the supply chain.

Keywords: maritime transport, container, transportation, dangerous goods, risks, data system, safety control.

Background. *Maritime container transportation is recognized as one of the most advanced types of cargo transportation. Being closely related to economic and administrative resources of the state, it has become a kind of macro-economic indicators, reflecting among other things the effects of international crises. The obvious advantage of this industry is the ability to transport almost the entire range of goods in universal and specialized containers that poses a very significant threat to safety in today's realities.*

Over the past 60 years, container capacity of ships increased from 400 to about 19 500 containers in conditional TEUs, that is almost 50 times. The largest current container ships cost more than 150 million, and cargoes carried on them simultaneously can cost several billion US dollars. The combination of a wide range of dangerous goods that can simultaneously be on board, make it in the literal sense of the word a «bomb» both financially and physically.

Whether this bomb explode or not, depends on the effort that international and national institutions will make to ensure safety of maritime container transportation.

Objective. *The objective of the author is to offer a comprehensive approach to safety of maritime container transportation.*

Methods. *The author uses general scientific and engineering methods, simulation, evaluation approach, comparative analysis.*

Results.

There is something to be afraid of

All general risks inherent in the shipping industry are applicable to the conditions of maritime container transportation. They include navigational hazards: collision, grounding; operational risks: fire, breakdown of equipment and machinery; external risks: impact of meteorological factors, acts of foreign aggression.

At the same time the specificity inherent in container transportation has its own unique risks associated with peculiarities of goods, transportation technology and loading and unloading operations:

– Risks of damage in case of violation of dangerous goods transportation technology – environmental pollution, including radiation and infection, explosion, fire, structural failure, personal injury, goods damage;

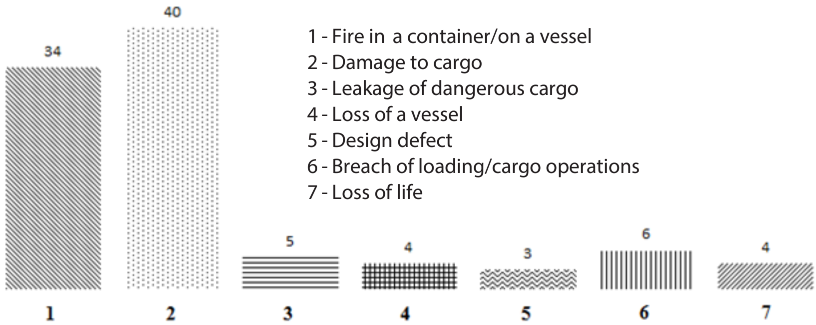
– Risks of damage in case of violation of refrigerated goods transportation – damage of costly cargo, breaking of cold-keeping container;

– Risks of damage in case of improper, in terms of weight loads on the body of the ship, placement of containers on board, loss of stability, irregularities in ship maneuvering, damaging its body, ship's destruction.

For professional risk assessment analysis of accidents and development of technical and organizational solutions to minimize the likelihood of such accidents in the future are required. Table 1 provides an overview of typical accidents of container ships, Pic. 1 – systematized kinds of accidents.

CINS: cause of incidents

In the field of maritime container transportation to assess the incidents with container ships and their cargoes, five years ago an information system CINS (Cargo Incident Notification System) was introduced. Its founders were five largest container carriers: Maersk, MSC, CMA CGM, Evergreen and Hapag Lloyd. Having passed the testing stage, CINS started full operation in September 2011. Now participants of this system are 19 companies, 14 of them are



Pic. 1. Analysis of typical accidents with container ships between 1997 and 2015, according to open sources on the Internet.

Table 1

Brief description of typical accidents involving container ships from 1997 to 2015

Ship (TEU)	Year	The nature of the accident
Contship France (1599)	1997	Fire of a container with calcium hypochlorite because of laying on top of the heated fuel tanks. It was believed that maximum permissible temperature of load heating is 55°C, and a fire occurred at 47°C.
MSC Carla	1997	The vessel underwent structural alterations – elongation of the body by 14 m. It got in hard storm and broke along to the joint weld at the site of insertion of additional sections. Shortly before that, the vessel had undergone extended examination by the classification society upon reaching 25 years of service.
Tiger Wave (1510)	1997	Fire of containers with calcium hypochlorite.
Sea Land Mariner (2816)	1998	As a result of welding explosion and fire of fumes of undeclared dangerous goods in the hold occurred. Two people died. The big damage to cargo and the ship. Leakage of cargo.
DG Harmony	1998	Fire of 10 containers with calcium hypochlorite. Transportation was carried out in accordance with IMDG Code, but the Code requirements were insufficient. Complete loss of cargo and the ship.
Aconcagua	1998	Fire of containers with calcium hypochlorite.
Maersk Mombasa	1998	Fire of containers with calcium hypochlorite.
Sea Express	1998	Fire of containers with calcium hypochlorite.
CMA Djakarta (2048)	1999	Fire of containers with calcium hypochlorite.
Kitano (3618)	2001	Fire of a container with activated carbon and caustic soda.
Hanjin Pennsylvania (4369)	2002	Explosion of containers with fireworks. People died. Extensive damage to the ship or cargo.
Punjab Senator (4545)	2005	Explosion of a container with batteries. The container was placed next to the heated fuel tank (70–80°C). Serious damage to cargo and the ship.
Hyundai Fortune (2181)	2006	Explosion of containers with dangerous goods (fireworks). Damage to cargo and the ship. Falling containers overboard.
MSC Napoli (4734)	2007	Destruction of the body in a storm. The total loss of the ship and a large part of cargo.
Maike D (660)	2008	Due to the lack of control over cargo operations the crane lifted a container fastened with the tank-container, in which there was hydrogen peroxide. As a result, the tank-container fell and was damaged. There was leakage of dangerous goods.
MOL Prosperity (6350)	2009	Fire of containers with dangerous goods in the hold.
Husky Racer (942)	2009	During cargo operations in the port stalling of 26 containers occurred, while 18 fell overboard. The cause of the incident was incorrect information about the weight of containers provided in the cargo plan.
Charlotte Maersk (7226)	2010	Fire of a container with methyl ethyl ketone peroxide. 160 containers were damaged. The vessel received minor damage.
MSC Flaminia (6732)	2012	Fire and explosion of containers with unreliable declared dangerous goods. Three people were killed. The big damage of cargo and ship.
Maersk Kinloss (6188)	2012	Leakage of cargo. There was a chemical explosion in a container with aluminum phosphide. Technology has been broken when loading the container. As a result, the contact of load to the surrounding air and moisture. This triggered a chemical reaction and a chemical explosion.
Amsterdam Bridge (4380)	2012	Fire of containers with dangerous cargo. The big damage to cargo and the ship.
Eline Enterprise (364)	2012	Leakage of ethylene gas from four containers.
Hansa Brandenburg (1740)	2013	Fire of containers with dangerous cargo. The big damage to cargo and the ship.
Eugen Maersk (15500)	2013	Fire of containers. According to the documents they transported general cargo.
MOL Comfort (8110)	2013	Crash, fire and total loss of the ship while sailing in storm conditions due to excess of load on the body due to violation of rules of loading.
Maersk Kampala (6978)	2013	Fire of containers. Damage to cargo and the ship.
Maersk Dellys (5089)	2013	Leakage of dangerous cargo from the container due to its damage.
Leda Trader (2442)	2014	Fire of a container with a car. Damage to the load.
Svendborg Maersk (8680)	2014	Loss of 520 containers, including with dangerous goods, during sailing in storm conditions. Environmental pollution. The danger to shipping.
Santa Rosa (1742)	2014	Fire of a container with charcoal. Damage to the load.
Patriarch (буксирный состав)	2014	Fire of containers on a towed container barge. Damage to the load.
Nothern Guard (4319)	2014	The explosion of the container in the hold. The death of a crew member. Damage to the load. Additional details were not disclosed.
Hanjin Athens (5618)	2014	Fire (over 200) of containers in the holds. Damage to the load.
COSCO Pride (13092)	2014	Fire of a container. Damage to the load.
Maersk Londrina (8700)	2015	The explosion of containers in the hold. Damage to the load. Additional details were not disclosed.
Hanjin Green Earth (13092)	2015	Fire of (over 60) containers. Damage to cargo and the ship. Additional details were not disclosed.
Pioneer Bay (505)	2015	Falling of a stack of 12 containers at the dock due to a violation of cargo operations technology. Damage to cargo, ship, port facilities.
Kamala (2011)	2015	Fire of containers presumably with general cargo. Damage to cargo and the ship.
Maersk Seoul (8400)	2015	Fire and explosion of containers. Additional details were not disclosed.
Alula (13100)	2015	Fire of containers. Damage to cargo and the ship.
Mareno (1174)	2015	Fire of a container with charcoal. Damage to the load.
Cape Moreton (2742)	2015	Fire of containers with sodium hydroxide in the hold of the ship. Damage to the load.

This list consists of 42 accidents. We can assume with certainty that the real number is much higher.

Table 2

Quantitative analysis of possible causes of accidents with containers according to CINS data

Possible cause of an accident	Number of accidents	Share (%)
Bad packaging	240	40
False declaration	162	27
Improper packaging	78	13
Violation of container handling	24	4
Improper placement of containers on board of the vessel	12	2
Other causes	78	13
The cause is not defined	6	1

Pic. 2. Loss of container MOL Comfort in the Arabian Sea.

carriers and five major international insurance companies and transport institutions.

The total number of accidents reported since the beginning of CINS activities in April 2013 (18 months) amounted to 600 episodes. Comparing the data on accidents with containers available in the public domain, with CINS data for internal use, it is easy to see that there is a deliberate concealment of information from the shipping companies. So, if we compare the figures for fires and explosions, the publicly available information is available on 18 cases from 1997 to April 2013, (192 months), but only for 18 months 2011–2013 CINS recorded 48 accidents of this type, i.e., almost 29 times greater than the rate of accidents in the month.

In a certain sense, this behavior of shipping companies is understandable. Since any accident is a very painful blow to their reputation, it harms the image and undermines the authority on the container market. This leads to a decrease in demand for the company's services and, accordingly, reduces the profitability of the business.

Analysis of CINS data on the possible causes of accidents with containers is shown in Table 2.

The most common accident scenarios for the carriage of containers by sea:

1. Loading of undeclared dangerous goods. The crew was not able to properly monitor its condition during transportation. The result – explosion, fire, pouring.

2. Violation of the rules of separation of containers with dangerous goods, due to false declaration. The result – explosion, fire, pouring.

3. Improper temperature indication, which must be maintained for safe carriage of cargo, in the documents on the refrigerated container. The result was costly cargo spoilage.

4. Loading of a refrigerated container so that the refrigeration unit was poured with seawater while the vessel sailing in storm conditions. The container went out of order and the goods deteriorated.

5. The use of a refrigerated container for transportation of expensive electronics as an ordinary general container. The crew, considering it is a current refrigerator, connected it to the power supply. Transported LCD TVs were frozen and went out of order.

6. Loading of a refrigerated container to an invalid location on board of the ship, to which the normal access is limited. As a result, the crew was unable to troubleshoot a malfunction of the container in the sea, and the cargo on it deteriorated.

7. Preparation of the unacceptable cargo plan by a port planner and inadequate control of cargo assistant over this. The vessel got unacceptable loads on the body, the main engine was working in a deformed state, and one of its sleeves was damaged.

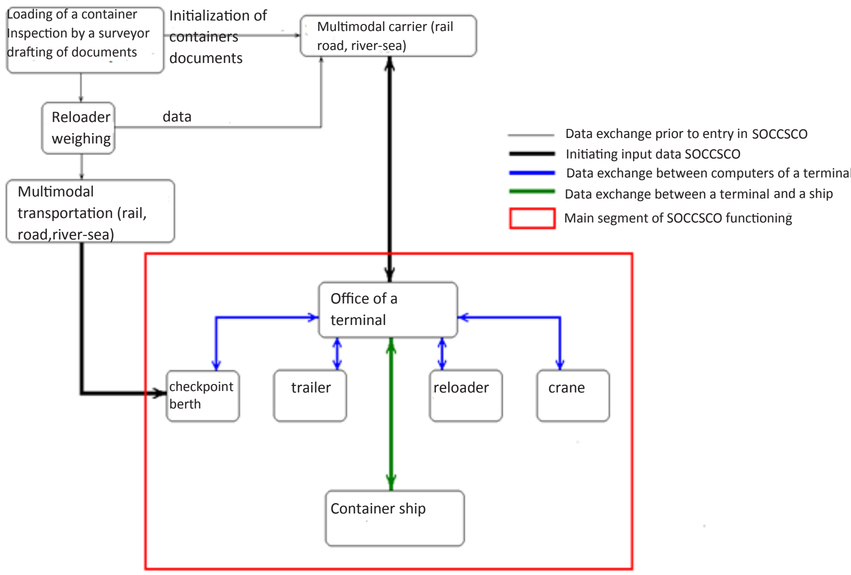
8. False declaration of weight of cargo in containers resulted after loading the vessel in a breach of the requirements of the body strength. The ship's body in storm conditions was damaged and the ship sank.

9. The use of improper technical condition of the container for dangerous goods of Class 8 (corrosive liquid). Fluid leaked, damaged the body and leaked overboard.

10. Failure to comply with the technology of cargo handling works led to what it was not observed that the container fastening means were not divided. As a result, the container was damaged and there was a leak of dangerous goods.

11. Undeclared container loading exceeding the allowable weight triggered when moving the overturning of forklift which operator was killed.

12. Failure to comply with visibility requirements from the navigation bridge because of excess of the height of the stack of containers on deck. The result –



Pic. 3. Scheme of data exchange within SOCCSCO.

a collision with a fishing vessel, which fell into the excessive dead zone of visibility.

13. Improper mounting of containers on deck. As a result, the ship got into the storm, lost some cargo, and was damaged.

In addition, it should be noted specially a high probability of accidents with containers due to navigational and operational errors. If the negative impact of stormy weather, in a general sense, is the same for all the vessels, the damage to containers with dangerous goods creates at this time an additional threat to safety of the ship, the cargo, the crew and the environment.

A similar situation is with ship collisions. In these cases, in addition to typical damage, can occur fires with dangerous goods, their leakage, pollution and harm to human health and life. The loss of containers overboard creates a very serious threat to navigation, especially in the busiest shipping arteries, as they may be a long time afloat in submerged condition when they cannot be found either visually or with the use of radar.

International sectoral database

Among organizational and technical solutions, which could help the prevention of accidents and neutralize the causes of accidents with container cargoes, there are at least five that deserve special attention. And the first among them is creation of an international sectoral database on accident in maritime container transportation.

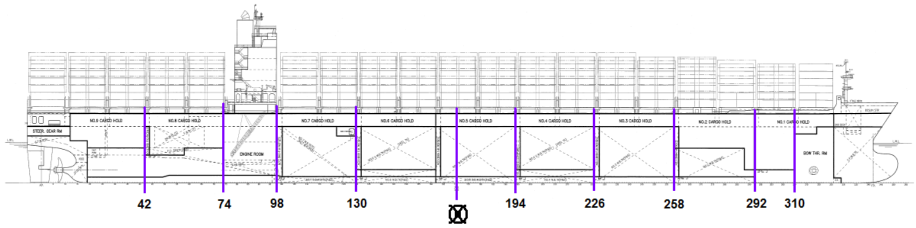
It is assumed that access to it can be obtained by any interested participant of maritime container traffic, past certain registration procedures. Such registration must exclude the possibility of entering unauthorized and inaccurate data into a database. The database must have a code structure, so that each accident could be codified in key parameters. By entering data into the system, it will be updated and will cover an increasingly wide range of occurred and potential accidents during transportation of containers.

Interested community can use international sectoral database on the principle of «learn from others' mistakes». Knowing about accidents that have already happened or could happen, being able to evaluate and analyze the associated risks, the competent member of container shipping market will avoid repetition of such trouble in his work. In addition, a fairly complete database will expand horizons in matters of forecasting potential risks through analogies with known occurrences.

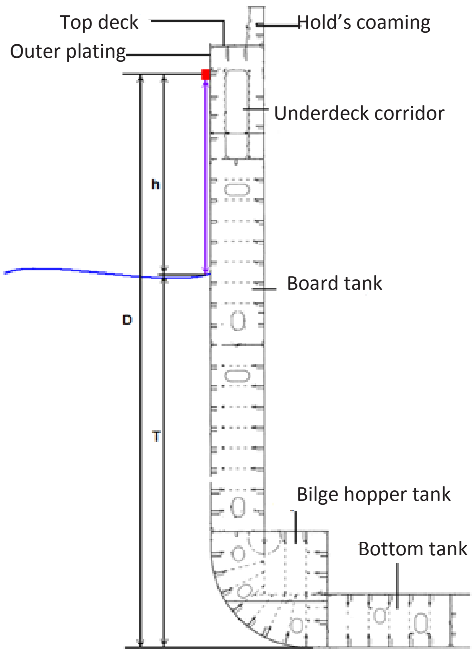
Initially, the database can be implemented within a shipping company, absorbing the experience of its own accidents in maritime transportation of containers and external accidents, which became known. The successful experience of implementation and use of such information within a single company will be a weighty argument in favor of extension of the system to the national, regional and international level.

Existing CINS is the best example to date of operation of a system similar in its plan. However, it is entirely voluntary and, in spite of a considerable list of participants is far from the global reach of the industry of container shipping.

Since in the containers accidents suffer all participants of the transport process and often the environment, it is advisable to reinforce CINS to have



Pic. 4. An example of the placement of sensors on frames.



Pic. 5. Principle diagram of draft sensor operation (cross-section of the vessel).

a proposed international database on accidents in maritime container transportation (IDB AMCT) as a tool to ensure safety of maritime navigation, regulated by relevant international conventions and international maritime institutions. That is, to get a real high-profile and recognized by the world community transport organization.

The system of operational control of cargo operations

Container transportation differs in the fact that it enables precise mathematical expression of processes of placement and movement of the container. The container has its individual number. In the container terminal each cargo container is placed on the site, which has its own address. On board the container enters a cell, which again has its own address. Re-loaders and cranes, also, have their numbers. This greatly facilitates digitization and programming of all operations with containers.

Modern container terminals, such as ECT in Rotterdam and CTA in Hamburg, use robotic means for moving the containers. This is possible precisely because for a robot a clear program can be set on which it will make a predetermined operation.

The main components of this system are:

– Computer modules mounted on each stage of transportation of the container within the terminal and on board of the ship, and integrated into a single communications network;

– Technical means for scanning an individual container number with optical character recognition function;

– Technical means to determine weight of the container.

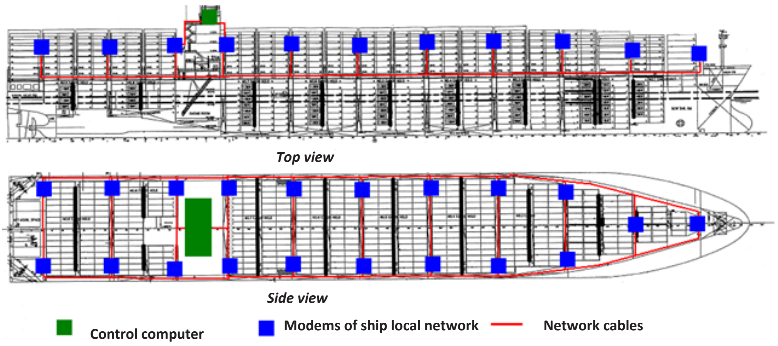
The principle of operation of the system of operational control of container ship cargo operations (SOCCSCO) lies in the fact that when the container arrives on the territory of marine container terminal through the checkpoint, equipment situated therein reads individual data of the container and automatically makes the originating post in SOCCSCO. Truck trailer or another vehicle gets the desired direction to the container area where the container is to be unloaded. The rear container re-loader with the system determining the weight of the container removes it from the trailer and sets on a given platform. Then the container weight is fixed up to 100–200 kg. These values are entered in SOCCSCO again.

Terminal planner, making the cargo plan takes into account the data on the container and its real weight. In accordance with the drawn up cargo plan the sequence of movement of the container prior to loading on the ship is determined. This sequence includes container delivery to the wharf area to the respective container crane, which then immerse the container in the appropriate cell on board.

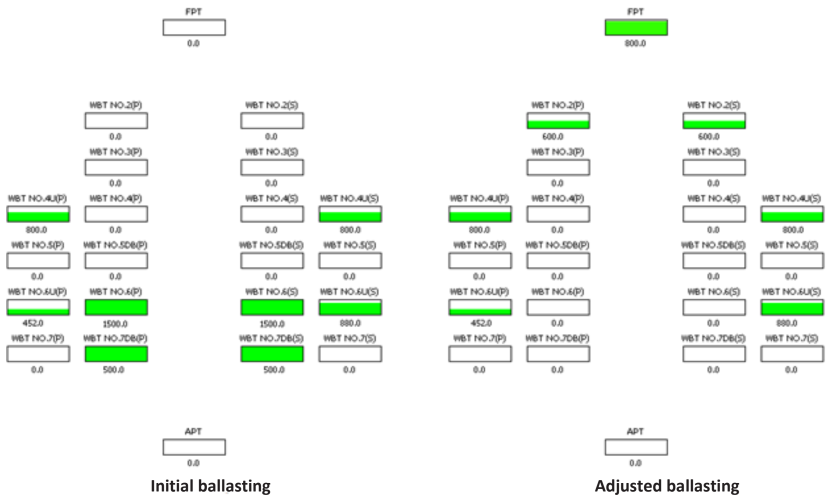
Lifting the container from the quay the crane re-defines its weight and once again scans the unique number that allows to virtually eliminate errors in the control system. After loading the container in a given cell there is a final update of its status in SOCCSCO with the computer. The resulting information is transmitted to the cargo computer of the container ship.

The scheme of interaction and communication within SOCCSCO is shown in Pic. 3.

The information provided on the vessel from SOCCSCO in real time, allows to update the state of the ship loading, its stability, sitting and load on the body. In addition, there is a constant comparison of actual loading with the cargo plan, which was granted to the ship by the terminal planner. In case of deviations from the plan the cargo program on ship will issue a warning. This function will be very useful for a cargo assistant, because it often happens that the vessel loading changes already in the process of



Pic. 6. The general scheme of ship local system of container safety monitoring.



Pic. 7. Example of adjustment of vessel ballasting to reduce stern draft by pumping ballast in head tanks and pumping surplus overboard.

cargo operations. And an updated cargo plan is transmitted to the ship with some delay.

Thanks to SOCCSCO deviations can be rapidly detected, and thus the corrective actions will be timely.

Body deformation control system

Operational control of the deformation of container body allows in real-time to get data about actual sitting of the ship and deformation processes.

System of sensors installed along the perimeter of the body at certain points, records the current draft of the vessel, together determines their profile and character of deformations.

Points to install the sensors are selected based on the characteristics of the ship's structure. Basically it is – in accordance with the document «Information on stability and strength of the ship» – the points for which the designers calculate strength. As a rule, they correspond to the frames, which are on the border of cargo holds and middle-ship frame.

Measurements of sensors in the current mode enter the ship's computer, where the profile of ship's draft is built, which are obtained by comparing deviations from the original theoretical plane of the vessel corresponding to the plane of the water line during vessel's trim on an even keel for a given displacement.

Different calculation algorithms may be applied. The deviations are usually specified as a percentage, with a maximum value of 100% corresponding to the maximum allowable value of deformation on this control frame or in the area between frames.

The principle of determining vessel's draft by sensors assumes an elementary computational algorithm:

$$T = D - h, \qquad (1)$$

where T is calculated draft, m;

D is height of the board side of the vessel from the keel plane to place of the sensor, m;

h is a distance measured by the sensor to the level of water surface.

The sensor according to the settings performs averaging of distance measurements to the water level. This is particularly important because the surface of the water is in stationary vibration and immediately taken measurement likely will not correspond to the true position of the level, while the averaged data based on multiple measurements will be accurate enough.

However, it should be noted that the system is operating at the time of berthing for cargo operations at berth. Condition of the water surface in the port is calmer than in the open sea. Therefore, averaging water level fluctuation increases measurement correctness.

Multiparameter monitoring

Complex in its nature multiparameter monitoring system for container safety is a set of sensors that enable real-time monitoring the state of the container and cargo loaded in it, as well as a communication channel and a control computer receiving and processing incoming signals.

The control system may comprise:

– Temperature sensor inside the container;

– Humidity sensor inside the container;

– Sensor-gaz analyzer of the atmosphere inside the container;

– Sensor of opening of the container doors;

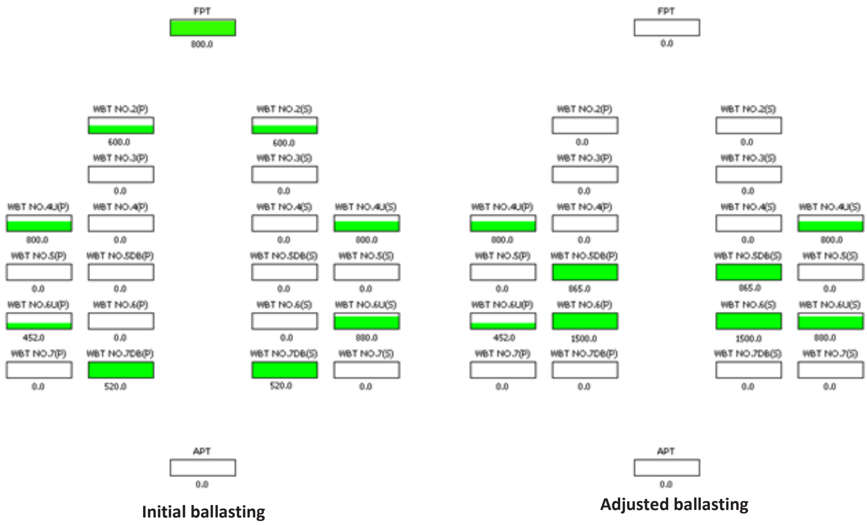
– Sensor of container geolocation in the system of global and local ship or terminal positioning.

All of these sensors are proposed to be combined structurally into a single unit to be placed inside the container. This unit can be installed by the manufacturer of the container, the cargo owner, shipper or container operator at his own request.

As a precedent here are suitable refrigerated containers, which are always connected to the ship's electrical grid to provide power to a freezer. At the same time via a data cable, which is combined with the power cable, the container is connected to a refrigerated container monitoring system, which is already used for many years in the ships.

For other types of containers it seems appropriate to use a combination of wireless and wired signal transmission method. In this case, the signal from the container's sensors through the antenna is transmitted wirelessly to one of the intermediate local shipboard routers mounted on the cargo deck, which are in turn connected with wires to a shipboard monitoring system including a control computer.

The output of the transmitting antenna should be placed on one of the doors of the container, because



Pic. 8. Example of adjustment of vessel ballasting to reduce vessel inflection vessel by pumping ballast from head and stern tanks in tanks located amidships and near it.

they are the most accessible and open part of it. Then developing constructive solutions anti-vandal protection should be envisaged.

Router of local shipboard system should be mounted on the top of the container fixing bridges.

Since modern container ships are highly electrified, there is no difficulty in laying network cables through the channels used, for example, for electrical cables for lighting ship deck.

Receiving monitoring data, it is possible to prevent including such incidents as:

– Fire of cargo in the container;

– Leakage of cargo;

– Damage of cargo due to temperature change mode and / or atmosphere inside the container;

– Unauthorized access to the container;

– The loss of the container during transportation.

The obvious advantage of multiparametric system is the fact that it can be implemented in the port terminal complex, and other modes of transport, including rail and road.

Monitoring stability of container

System of calculation and control of stability of a container ship with decision making support function is designed to assist the crew of a container ship in a choice of options, providing the required parameters of stability, sitting and strength of the ship's body.

To calculate stability all modern container ships use special software designed for this type of vessels.

Cargo program is based on the hydrostatic characteristics of the vessel and uses the same data as presented in the document «Information on stability and strength». The principle of a cargo program is associated with exchange of standardized packages of requirements and is presented in the description of SOCCSCO.

An additional software module, analyzing the state of loading of the ship and the identified deficiencies, calculates the options of bringing the ship to the parameters that are defined by the operator. What is necessary to do for a crew member to bring the ship to appropriate parameters when setting the appropriate algorithm, the program can perform.

Among negative factors that the system is ready to respond:

1) discrepancy of ship draft with set parameters;

2) excess of permissible deformation of the body;

3) excess of local strength of the body;

4) insufficient or excessive stability of the vessel;

5) lack of visibility from the navigation bridge;

6) conflict in placement and separation of containers with dangerous goods;

7) placement of refrigerated containers in places that are not designed for their carriage.

The main instruments owned by the crew to correct the negative load factors are:

– Ballasting;

– Corresponding distribution of the bunker;

– Moving the containers on the ship.

It is obvious that ballasting and distribution of the bunker allow to eliminate negative factors of 1–5. In this distribution of the bunker is much less effective means and cannot be used in all cases.

Moving of containers on board helps to eliminate all the negative factors. This large-scale movement of goods is not only inappropriate, but also not very applicable because it can disrupt the essence of the planned shipment. Therefore, in a similar manner only negative factors 6 and 7 can actually be eliminated.

It should be noted that the number of containers with dangerous goods and refrigerated units is usually small relative to the total number of containers on the ship and is measured by several tens or hundreds. And in most cases conflicts with their placement are easier to be removed manually, without the use of automated tools. In addition, a manual way to solve such problems is the most preferred since attempts to introduce into the program once all the available data can be very time-consuming, or even impossible.

A possible algorithm for decision-making to bring the vessel to a given sitting:

1. Determination of the difference between the desired and the actual draft (head, stern, midsection).

2. Changing draft considering the fact that its increase / decrease on the same end of the vessel does not necessarily lead to the same increase / decrease in draft on the other end.

3. Determination of the most effective ballast tanks for ballasting, referring to those pitching couple that will be most effective for a given task.

4. The calculation of the amount of ballast required for acceptance or haulage, according to the criterion of minimizing inefficient in its volume on board.

5. Control calculation of draft of the vessel to the new scheme ballasting.

6. Comparison with predetermined conditions.

7. Adjustment of ballast operations or its termination.

An exemplary algorithm for decision-making to reduce the bending moment of the vessel (inflection)

1. Assessment of the difference between the desired and the actual draft (head, stern, midsection).

2. Determination of the amount of ballast to be taken in the tanks amidships or in the vicinity of the tank or haul from tanks near the ends of the vessel.

3. Calculation of ballast required for acceptance or haulage, according to the criterion of minimizing inefficient in its volume on board.

4. Control calculation of ship's draft for the new ballasting scheme.

5. Comparison with predetermined conditions.

6. Adjustment of ballast operations or its termination.

These simplified algorithms can be easily set in the cargo program. For example, if it is preferable to solve the problem with providing adequate visibility from the navigation bridge by ballasting the vessel, it can be specified in the program. Then it will pick up just such solutions, and not to offer overload containers, limiting visibility.

The program may provide several solutions and the operator has to select the most effective ones, based on the characteristics of the situation and applicable requirements.

Conclusion. *With increasing size of ships and container capacity directly the probability of accidents increases proportionally. The number of containers with dangerous goods, which are transported on the ship simultaneously, grows. Given the fact that the violation of the rules of marine transportation of containers occurs more often, risks of accidents increase, in spite of implementation of the international risk assessment practices in the shipping industry.*

Container ships of near future, which will be able to take on board more than 20 000 TEU, will be powerful and extremely dangerous objects. And if the industry does not develop or implement effective technical and organizational solutions to reduce the accident rate, we should expect more large-scale technological and environmental disasters.

Only a responsible approach of all participants in maritime container transportation, aimed at identifying and eradicating the root causes of incidents and their adequate information support will help to take control of accidents in the sector and reduce it to a minimum.

Development and introduction of technical and organizational systems related to identification of negative factors and threats to safety in their early stages, will allow to control the safety of maritime container transportation.

It is obvious that implementation of such systems will be effective only if it is supported by all participants – shipping and land transport companies, port systems and logistics centers.

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Article received 09.12.2015, accepted 20.04.2016.

The author is a prize winner of the contest «Young transport scientists and researchers» organized by the Ministry of Transport of the Russian Federation within the framework of «Transport Week – 2015». The work was presented during the final round of the contest held on December 2, 2015 in Moscow State University of Railway Engineering (MIIT) and got the first place in nomination «Innovations in traffic control, energy saving, and safety as main vector of transport developments».