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Fundamental Concepts of Deck Cargo Handling and Transportation Safety

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Abstract

The transportation of various cargoes, including equipment, machinery, modules, vessels and even steel products, on the upper open decks of seagoing ships presents unique challenges, especially in adverse weather conditions. Improper stowage and securing of deck cargoes are the main causes of a significant number of accidents at sea, resulting not only in financial losses but, most importantly, in tragic loss of life, both at sea and during port operations. This underscores the urgent need to improve methods and practices related to cargo stowage and securing, which remains one of the most risky aspects of maritime operations. This paper presents a comprehensive research initiative that addresses the complex aspects of planning, stowage and maritime transportation of deck cargo. It examines the key determinants and factors affecting the safety of the transportation process and provides a thorough analysis of the challenges encountered during deck cargo operations. The findings of the study enable the implementation of robust safety measures to safeguard property and lives in this vital sector of maritime logistics.

Keywords: deck cargo, safety of transportation, shipping process, ship operations, cargo condition, maritime transport, chartering, ship stability, adverse weather conditions, cargo handling.

1. Introduction

In today's maritime industry, there is a paramount need for fast, reliable and high quality cargo delivery. As transportation volumes grow and the logistics industry expands, the risks associated with transportation processes and potential threats to cargo security increase proportionately. It should be noted that many of these risks depend on factors such as the mode of transportation chosen, the geographic extent of transportation routes, and the unique characteristics of the cargo being transported.

Despite the fact that carriage of cargo on deck is at shippers or charterers' risk, excluding liability of the ship-owner, agreement on such carriage is allowed only if it is

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stipulated by the contract, popularity of this type of carriage remains very relevant. This is due to the high level of freight of cargo units, which cannot be safely allocated in cargo spaces below deck. The term "deck cargo" refers to that type of object or commodity which is accepted for carriage on the open deck and/or hatches of a ship and which is exposed to the outside environment. Deck cargo can be exposed to atmospheric precipitation or wind pressure and waves impact in rough seas for extended periods. Consequently, the proper stowage and securing of deck cargo (Stowage of breakbulk 2006, Shigunov et al. 2010) is critical to the safety of human life at sea, the vessel, and the environment. A combination of forces, created by accelerations in stormy weather, act on the ship and cargo during transportation at sea, which in rough seas generate most of the problems associated with the securing systems and consequently the integrity of the ship's structures. Therefore, the hazards arising from these phenomena should be considered by developing and adopting measures, which at the initial stage can ensure proper placement and securing of cargo on the ship, and will contribute to measures to reduce the amplitude and frequency of ship's rolling (Ghamari et al. 2020, Peşman & Taylan 2012).

Carriage of deck cargo on ships is associated with a wide range of hazards that require appropriate measures to ensure the safety of the ship and crew, as well as the safety of the cargo during loading, stowage and lashing. In addition, among the important aspects are not only the process of maritime transportation, but also a set of preparatory activities in the port during cargo operations.

Considerable attention has been paid to the comprehensive coverage of the aspects of deck cargo transportation process, in which the specific issues of their safety were considered from the side of regulatory documents, manuals and guidelines as well as proposed interpretations and amendments (IMO Res. A715, IMO Res. A714, IMO Res. A749, Kaps & Andersson 2017). When transporting deck cargo, attention should be paid to local, national or international laws and regulations as well as any changes in laws, regulations, administrative requirements, the introduction of which may affect the transport process (Hjalmarsson 2012). Issues at improving the safety of navigation of ships based on the development of technology for securing packaged timber cargo and actual issues of ensuring the safety of maritime transportation of goods reviewed in (Anosov 2013, Karpovich 2004). Carrier's liability for the carriage of deck cargo matters, the difficulties arises in attempting to determine the carrier's liability in the event of loss or damage to cargo during carriage by sea examined in (Clark 2019, Djadjev 2017, Glass & Hodges 2010).

Considering that, a large number of containers constitute deck cargo a number of scientific works devoted to the rule development for container stowage on deck, numerical simulation of container stacks dynamics under typical motion excitation (Wolf et al. 2011, Li et al. 2019, Kahl et al. 2008).

The influence of loafing, stowage and discharging the loads on trim and stability, aspects of ship strength, squat and trim, as well as stresses and forces (Tsurenko 2019, Barrass & Derrett 2012). Bulky sea transport based on ship response weather routing, impact of heavy weather on cargo damages, efficiency of ship operation under various weather conditions studied in (Rodrigues et al. 2018, Onyshchenko & Melnyk 2022, Rathje et al. 2018). General ship's safety issues and aspects concerning the cargo transportation by sea (Turon et al. 2019, Melnyk & Malaksiano 2020, Uchacz & Galor 2013, Golikov et al. 2018). Onishchenko et al. (2022) considered technical and operational strategies aimed at improving the environmental and energy efficiency of ships. Rudenko et al. (2022) discusses a multicriteria approach for determining the optimal composition of technical means in the design of sea grain terminals.

Zhou et al. (2018) tackle an important aspect of safety in their study, focusing on the performance of a bridge deck when subjected to the impact of a falling cargo from a passing truck sheds light on crucial safety considerations in cargo handling. Sankaranarayana's comprehensive work (2022) emphasizes the prevention of occupational and other accidents during cargo-related operations onboard ships. Sasa et al. (2023) contribute to safety assessments in ferry operations under challenging sea conditions providing a valuable evaluation of lashed trailer motions, offering insights for safer maritime transportation. Melnyk et al. (2023) propose a method for shipboard operations risk assessment quality evaluation. Konon et al. (2023) present simulation modeling of heat exchange processes between containerized cargoes. Landamore et al. (2009) outline the concept of Create3S and possible solution routes for hull form optimization. Finally, Putra et al. (2023) conduct a cyber threat analysis of maritime cybersecurity using AHP-Topsis.

This study opens a new direction in the theoretical application of practical deck cargo handling with simultaneous improvement of transportation safety. An integrated, synergetic approach to deck handling of various types of cargoes, ranging from bulk, freestanding complex configurations to cargoes of predetermined complex structure, such as metal, various types of pellets and other atypical cargoes, is presented for the first time. Such a synergetic approach, which is proposed to be realized on the basis of cargo plan construction opens completely new horizons for further scientific research aimed at improving the safety of cargo transportation. The cargo handling algorithm proposed in the article is implemented, among other things, by taking into account a greater number of components and factors, which makes it possible to consciously carry out cargo loading according to a theoretically justified cargo plan, where for the first time a number of factors taking into account the components of wind-wave disturbances, ship design features, etc. are simultaneously taken into account. At the same time, these factors and components were not given due attention in previous works. Thus, it should be emphasized that the contribution of the authors at this stage is not only in the complex consideration of new influencing factors on transportation safety, but also in taking into account significant changes in the legislative framework, which differs for different countries and ports, as well as in the human factor.

2. Methodology

According to the World Shipping Council (WSC) an average of 1,382 containers are lost at sea each year, and these figures do not include general cargo that is transported by sea on the deck of non-container ship types, whose value can run into the hundreds of thousands of dollars.

Reports submitted by the insurance community on the main types of claims for damage or loss of cargo are based on the fact that severe weather conditions were the cause of the incident. Claim types where heavy weather is a factor:

- Physical damage: cargo shifting, breaking, collapsing, falling;
- Wet damage: cargo affected by water ingress to cargo spaces;
- Cargo lost overboard: deck cargoes;
- Contamination resulting from physical damage of adjacent cargo.

All deck cargoes can be subdivided into the following groups:

- hazardous, which include: explosives, compressed and liquefied gases, flammable solids and liquids, oxidizing, poisonous, radioactive and corrosive substances. Such cargoes, if they are not transported on specialized ships could be loaded on deck and are freely accessible;
- emit pungent odors;
- waterproof (iron, pipes);
- bulky: watercraft, locomotives, railroad cars, machine parts, boilers, cars, planes, tanks, etc;
- timber;
- livestock cargo and poultry that are transported in stables, enclosures, and cages.

As the analysis of scientific works and statistical data shows, the problem of deck cargo shifting often occurs due to violations of the technology of cargo transportation by sea and under the influence of dynamic loads when the ship is sailing in adverse weather conditions.

According to the mechanical model of displacement, all types of displaceable cargoes are classified as follows: absolutely solid body (containers, roll-trailers, large-sized and other so called cargo places); solid cohesive loose medium (bulk cargoes and grains); discrete entity (packages, rolled metal products, scrap metal, etc.).

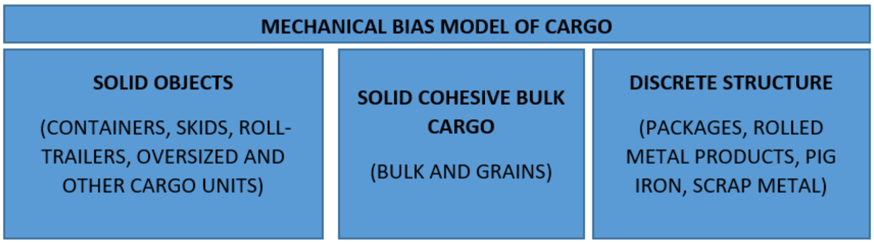

Figure1: Mechanical bias model of cargo.

Loads, namely rolling vehicles, railroad wagons, containers, platforms, which are close to the state of an absolutely solid body, remain on board under the action of forces, which do not depend on the properties of the cargo itself.

In the case of composite consignment transportation, the stability of a stable stack is ensured primarily by reliable securing of its surface. Securing the surface of the stack can be done in a block: by tightly stacking stable cargo.

Notwithstanding the fact that the carrier's liability is excluded for loss or damage to the cargo carried on deck the Master of the ship shall make maximum efforts to ensure the safety of the transportation of the deck cargo, since it is directly related to the safety of the ship. In case of loading deck cargo, information about which is absent in the ship's cargo securing manual or in regulatory documents as for the rules and conditions of subject deck cargo transportation, the Master should study the cargo information provided by the shipper. In the absence of such information the Master has the right to refuse to accept the cargo for carriage or to request the assistance of experts from a certified survey company. If there are no conditions for the stowage and securing of the cargo on board, which ensure its safe transportation and, first of all, its non-shifting during the voyage, the Master has the right to reject the carriage of the cargo.

Regarding the content of the information about the cargo, which is planned to be transported by sea, it should usually consist of the following parts:

1. Information about participants of maritime transportation of cargo: consignor, consignee and carrier with indication of their exact names and requisites; names of ports of departure and destination.

2. Cargo description with indication of: full name with a necessary specification of the number of regulatory documents for production, manufacturing company; shape, dimensions and weight of cargo packages; types and description of packing, including availability and strength of devices used for cargo overload and securing; cargo transport characteristics (specific loading volume, allowable stacking height, static stability angle, pair friction coefficients: chemical properties and other potential hazards.

3. Requirements and measures to ensure the safety of transportation, including requirements for stowage and securing of cargo, instructions on the accompanying cargo declarations, certificates and other documents. Stowage and securing requirements - this section must contain a list of cargo securing measures or a reference to a document containing such requirements, for example cargo securing guidelines.

4. Additional documents - this section is to be filled in, if the cargo is shipped in the form of enlarged packages, formed with the use of load-carrying packing devices (document about the strength of load-carrying packing devices), or in the vehicles of enlargement under the sender's seals.

2.1 Development of a conceptual model for organizing the deck cargo handling process

Summarizing practical experience it is necessary to develop a conceptual model providing stage-by-stage planning and organization of cargo operations with deck cargoes that takes into account mass and geometric parameters of cargoes and technical and technological aspects of ship loading procedure (Fig.2).

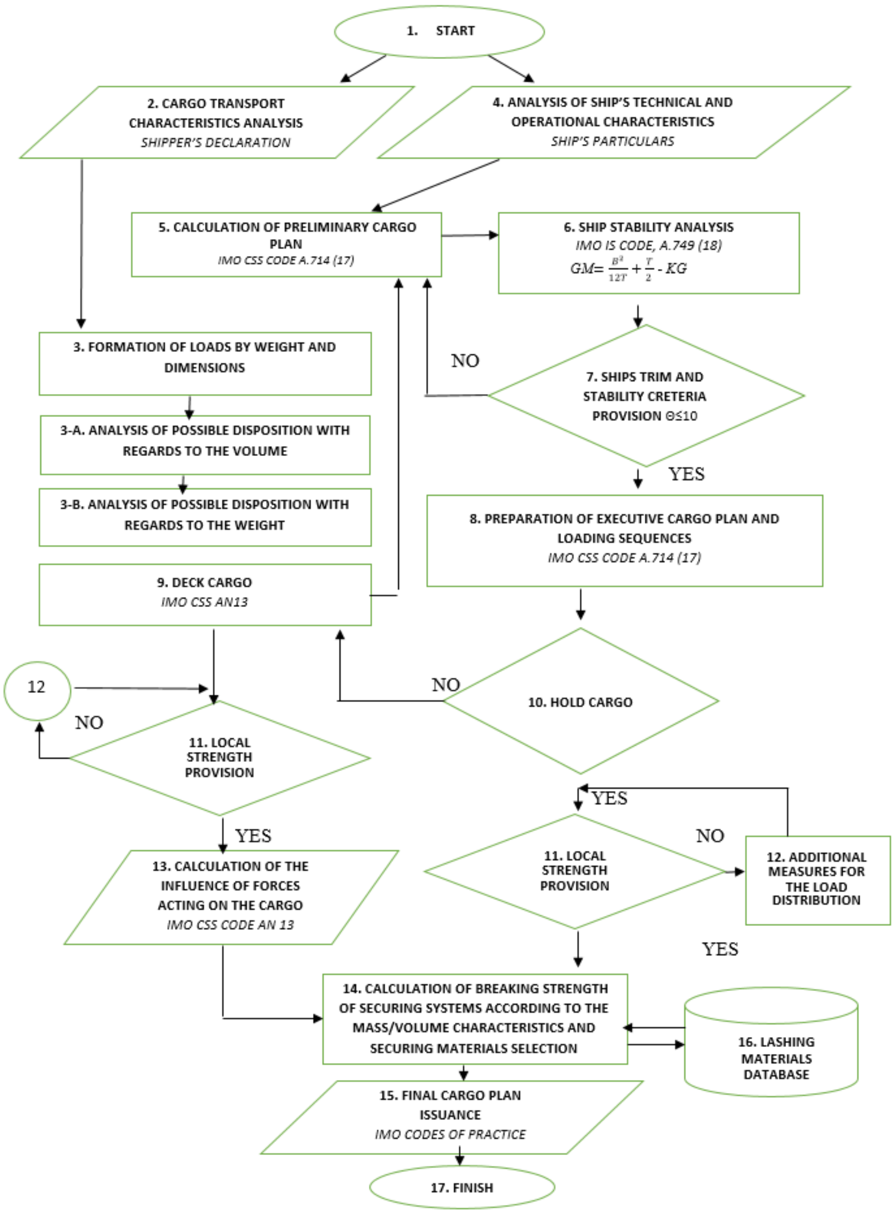

Figure 2: Conceptual model of deck cargo handling arrangement.

Proceeding from the analysis of transport (mass-dimensional) characteristics of cargo to be shipped on the open deck (2) there is a need for the division of such cargoes into the groups (3), based on the assumption that cargoes can be oversized but at the same time have different weights. Taking into account the limitation of ship's cargo handling facilities (average maximum capacity of a single crane in the range of 25 tons, coupled cranes reaches - 45 tons), it is possible to classify them into the following groups: standalone cargo units, combined shipment group including oversized and heavy cargoes and a group that consists of cargo lots of unitized size and weight. That will allows selecting the necessary cargo gears with required load capacity and handling capabilities. Further, in the course of comparative analysis of cargo groups, technical, and operational characteristics of the ship it is possible to calculate the preliminary cargo plan (5) by taking into account the features and properties of these cargo groups (3, 3A, 3B). If the results of the examination of the ship's trim and stability calculations meet the criteria and the loading is safe (6), proceed to the formation of the executive loading plan versions and creation of the stages of loading sequence and ballasting of the ship if necessary (8). The cargo plan for oversized and heavy items should be made on the basis of an individual approach to their disposition either on top of hatch covers or on the main deck areas. Additionally, local and longitudinal strength, understanding of loading and lashing requirements, ability to use shipboard or shore-based cargo-handling machinery, ensuring a safe transportation and unloading process in the port of destination are taken into account. In accordance with dimensions of open decks, depending on ship type, geometric dimensions of hatch covers or any other transportation requirements, cargo can be accepted for loading as bilge or deck cargo (9,10). In case the cargo is accepted for transportation on the open deck, the local strength calculations of the deck structure and hatch covers (11) are made and in case of overloading the loads should be distributed by constructing a bed or a platform of solid wood or metal profile (12).

After that, on the basis of calculations of forces acting on deck cargo during the process of sea transport (13) and assessment of efficiency of the proposed methods of securing, the analysis of deck cargo securing scheme, material selection and calculations of rope strength and local strength of upper deck (14) are made. The results of these calculations are used to select the lashing equipment and dunnage material (16). Upon completion of the lashing process, a final cargo plan or a graphical scheme is drawn up indicating the detailed location of the cargo units at the appropriate scale in relation to their locations to the ship's decks or hatches (15).

When checking the condition of loaded deck cargoes, attention should be paid to: indications of their shifting; loosening or breakage of securing systems; damage or deformation of packaging structures; presence of dynamic contacts of cargo units with each other and with ship structures; redistribution of loads resulting from breakage of securing elements, dunnage materials condition affecting strength of ship structures, cargo and its lashing; sweating of cargo and ship structures; other conditions and circumstances which may have an adverse effect on cargo condition and its quality. If any deficiencies are detected, measures should be taken to eliminate them and, if necessary, additional cargo securing should be performed. The results of cargo condition inspection shall be recorded in the ship's log.

2.2 Assessment of the influence of forces acting on deck cargoes during their transportation by sea

During the shipping of cargoes by sea on the weather deck of seagoing ships, they are subjected to the following forces such as own weight; friction between the cargo and the deck or dunnage; inertia resulting from the ship being on the rough sea surface; wind pressure; wave impact; buoyancy resulting from waves rolling on the deck (Fig.3)

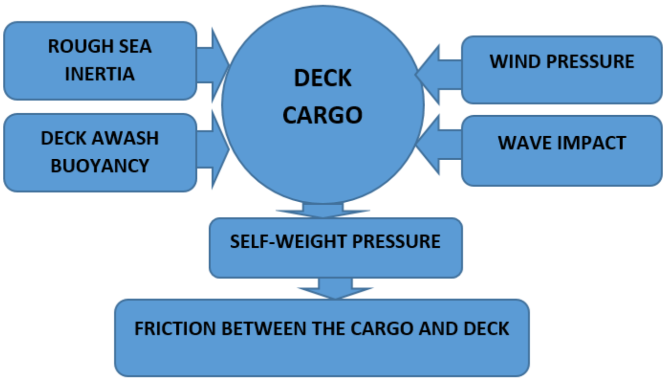

Figure 3: Forces acting on deck cargo during transportation.

During adverse weather conditions, when the ship is on an uneven sea surface, it experiences oscillations along three axes where movements known as yaw, roll and pitch occur. In addition to that, during rough sea, the vessel participates in orbital motion together with water particles. Respectively all three kinds of motion, being a phenomenon of periodic nature, cause inertial forces reaching sometimes large values, while among these kinds of pitch and roll, the vertical yaw causes minor inertial forces, which are usually neglected and their inertial forces are not considered significant. The ship may also be subject to the following phenomena: - dynamic loads on the hull due to shear forces, bending & torsion moments, slamming; - flooding (green water, shipping water); - crew performance reduction; - speed loss; - propeller emersion, propeller racing;

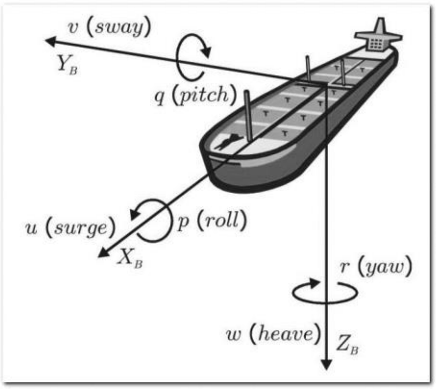

Figure 4: Ship's axis of motion in stormy weather.

Although all of the above inertial forces act on the ship and the objects on it, they also affect the deck cargoes. The main requirements for positioning, stowage and calculation of deck cargo securing facilities reduce to the fact that the secured cargo and the ship's hull constitute one system, a single unit cargo-vessel, so inertial forces acting on the vessel in equal degree act on the cargo. The accelerations acting on a ship in rough seas consist of a combination of longitudinal, vertical, and prevailing transverse motions. Moreover, the longitudinal and vertical accelerations may coincide in their maximum values on the ship, since they are both direct results of the roll and yaw motions, which leads to displacement and tipping of the cargo. The forces created by these accelerations produce most of the problems associated with cargo securing systems. The hazards arising from these forces must be addressed by responding appropriately to ensure that the cargo is properly stowed and secured on board the ship so that the amplitude and frequency of the ship's pitching and rolling is reduced in the future.

When calculating the stability of an individual cargo item, such as a container, the inertial effects of that item should not be considered as part of the inertial effects of the whole ship. This is because when analyzing individual cargo spaces, it is necessary to focus on their own inertia and its effect on the stability of the ship as a whole.

However, when distributing cargoes throughout the ship and determining the overall stability, the inertial effects of individual cargo spaces must be considered in the context of the entire ship. This is important to ensure the overall stability of the vessel and to prevent undesirable shifts in the center of gravity. Thus, when analyzing the stability of a ship, it is necessary to distinguish between calculations related to individual cargo spaces and the overall stability of the ship considering all cargo elements.

To estimate the individual components of the total force acting on a load, calculations must be made to determine each component of that force in this order:

Table 1: Factors Affecting Deck Cargo Stability.

Factors	Affected Aspects
Components of the weight	- Center of gravity position
	- Transverse stability
	- Longitudinal stability
	- Lateral stability
Components of the forces of inertia	- Roll motion
	- Pitch motion
	- Yaw motion
Force of wind pressure	- Heel angle under wind load
	- Sway motion due to wind forces
	- Lurch motion due to wind forces

Based on technique, proposed by Prof. Blagoveshchenskiy, examine the forces acting on deck cargoes during their transportation by sea. Assuming the worst scenario of pitch and roll impact, in which the vessel gets the largest (maximum) heeling angle and trim angle at the top and at the bottom of the wave. The projections of the inertial forces due to the orbital motion of the ship on the wave, in the directions parallel to the adopted coordinate axes, will be equal for the onboard rolling:

$$F_y = m\frac{4\pi^2}{\tau^2} r\sin\theta \max \quad ; \tag{1}$$

$$F_z = m\frac{4\pi^2}{\tau^2} r\cos\theta \max \quad ; \tag{2}$$

for onboard pitching:

$$F_x = m\frac{4\pi^2}{\tau^2} r\sin\phi \max \quad ; \tag{3}$$

$$F_z = m\frac{4\pi^2}{\tau^2} r\cos\phi \max \quad ; \tag{4}$$

Where: m-deck cargo, r-orbital radius of ship's center of gravity motion equal to half of the wave height, θ – maximum angle of heel, ϕ – maximum angle of trim τ - mass of the part of the ship considered;

For the components of the inertial forces in the direction of the OY and OZ axes, they are as follows:

$$F_{OY} = F_y = m\frac{4\pi^2}{{T_1}^2}(\theta \max z + r\sin\theta \max) \qquad ; \qquad (5)$$

$$F_{OZ} = F_z = m\frac{4\pi^2}{{T_1}^2}(\theta \max y + r\cos\theta \max) \qquad ; \qquad (6)$$

Where: T - the period of the ship's free motion T^1 (pitch) and T^2 (roll) can be determined from observations or by approximate formulas.

For the components of the inertial forces in the direction of the OX and OZ axes, they are as follows:

$$F_{OX} = F_x = m\frac{4\pi^2}{{T_2}^2}(\phi \max z + r\sin\phi \max) \qquad ; \qquad (7)$$

$$F_{OZ} = F_z = m\frac{4\pi^2}{{T_2}^2}(\phi \max x + r\cos\phi \max) \qquad ; \qquad (8)$$

The wind pressure on the cargo is defined as the product of the pressure per square meter by the surface area exposed to the wind. In order to account for the effect of the wind together with other forces, it is assumed that the wind blows in the direction that contributes to the joint shifting of the cargo, perpendicular to the board for lateral rolling and along the ship for pitching. The forces thus obtained are added to the inertial and weight forces.

The friction forces always act against the motion, hence they reduce the effect of the other horizontal forces. The wind pressure can be determined by considering the meteorological conditions of the forthcoming voyage or can be assumed to be 100 kg/cm², which corresponds to a wind of 12 Beaufort scale.

The total forces acting on the OY and OZ axes during the onboard rolling are determined by the following expressions:

$$F_{OY} = \frac{M4\pi^2}{g{T_2}^2}(\theta\max z + r\sin\theta\max) + M\sin\theta\max + P_1; \quad (9)$$

$$F_{OZ} = \frac{M4\pi^2}{g{T_2}^2}(\theta\max y + r\cos\theta\max) + M\cos\theta\max. \qquad (10)$$

The total forces acting on the OX and OZ axes during the pitching motion will be equal:

$$F_{OX} = \frac{M4\pi^2}{g{T_2}^2}(\phi\max z + r\sin\phi\max) + M\sin\phi\max + P_2; \ (11)$$

$$F_{OZ} = \frac{M4\pi^2}{g{T_2}^2}(\phi\max y + r\cos\phi\max) + M\cos\phi\max. \qquad (12)$$

Where: *M* – weight of deck cargo; *g* – gravity acceleration; P^1 and P^2 - wind pressure directed perpendicularly to the diametric plane and along it, respectively;

In these formulas, the term in parentheses represents the inertial forces, the second term the weight of the load, and the third term the wind pressure. Friction forces are not taken into account due to the difficulty of determining their effect. Neglecting friction forces gives an error in the safe direction. As can be seen from the above formulas, the forces acting on deck cargo are variable in sign and magnitude. In addition, in all cases, there are forces perpendicular to the deck, which exert pressure on it, causing some stresses in the structural elements of the deck.

The proposed calculation of forces according to the method of Prof. Blagoveshchensky is only a part of the conceptual model of the deck loading and unloading organization, presented in Fig. 2. in which the authors for the first time proposed to calculate and take into account the friction forces at displacements of cargoes on the deck. This factor significantly affects the methods and materials of cargo fastening, as well as possible deviations in the case of rolling, shifting and other disturbances arising during voyages. Consideration of these factors is especially important in transportation of oversized and complicated cargoes.

The presented technique is an integral basis for iterative calculation of loads (depending on the stowage conditions) duting the cargo plan elaboaration, but considering new components and factors (mechanical movement of cargoes - Figure 1, set of forces acting on deck cargo during transportation - Figure 3, stability coefficients - Table 1 and others). In addition to this, Professor Blagoveshchensky's methodology could not take into account the new requirements set out in IMO Resolution A.715(17), IMO Resolution A.714(17), the new Code of Safe Practice for the Placement and Fastening of Cargoes, IMO Resolution A.749(18) and other regulatory documents. For this reason, simultaneous (synergistic) consideration of a number of factors above, including the methodology described (1-12, but with friction forces), as one element of the preliminary assessment of forces.

The graph on Figure 5 shows the relationship between wind force and roll angle for a 20-ton deck cargo in a pure roll condition. As can be seen from the graph, the roll angle increases markedly with increasing wind force. This graph clearly demonstrates the effect of wind on the stability of the vessel. The trend shows a non-linear relationship, indicating that increasing wind force leads to disproportionately large roll angles.

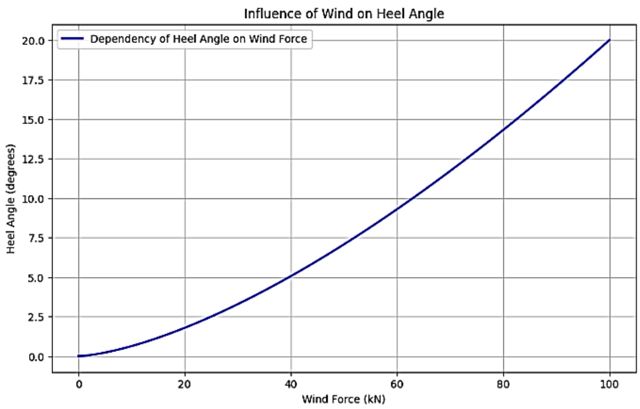

Figure 5: Influence of wind force on angle of heel.

As it is known, taking a load on board a ship above the waterline reduces its initial stability. That is, a vessel's ability to withstand external forces that cause it to roll and pitch at small angles of inclination. If the center of gravity of the cargo is placed exactly above the center of gravity of the waterline, no list or trim is produced by placing such cargo. However, when the cargo is picked up closer to the extremities or asymmetrically along the sides, the heeling and righting moments will occur.

In practical scenarios, especially when loading cargoes of significant mass, a specialized metacentric diagram proves invaluable for quickly and accurately determining key parameters such as transverse metacentric approximation (*Zm*), draft increment, new center of gravity approximation (*G*) after cargo loading and transverse metacentric height (h_1) at different drafts and ship displacements. This diagram is based on approximations of the ship's center of gravity calculated at different drafts.

This approach allows for a comprehensive evaluation of the effect of a heavy load on the initial stability of the vessel. Using graph analytical methods, a new value of the center of gravity approximation can be determined and the transverse metacentric approximation can be determined. The transverse metacentric radius, which is critical to understanding stability, is essentially the difference between these approximations (*Zm* and *D*), as shown in Figure 6. Thus, through the construction and analysis of this specialized diagram, deck officers can effectively manage the complexities of cargo loading and ensure the stability and safety of the vessel.

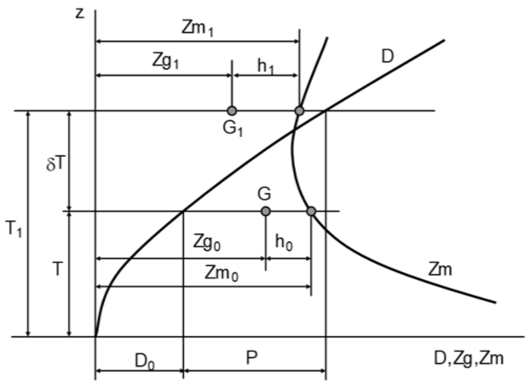

Figure 6: Metacentric diagram.

To ensure proper stability, the vessel should be ballasted, preferably in bottom tanks, and, if necessary, fuel transferred and other ballast tanks pressurized before starting to load deck cargo of considerable weight.

Particular care must be taken to ensure the vessel's trim and stability during the final stage of deck cargo loading. The maximum permissible height of deck cargo must be specified in the ship's stability information. The moment of cargo loading completion can also be determined by a practical method, which consists in the following: simultaneously the cargo is hoisted from one side, which mass on each of the cranes must be the same. If the vessel gets a list of 3-4° while lifting, further loading should be stopped. While the ship is sailing with any deck cargo, the securing systems must be continuously monitored and the resulting slack in the lines is promptly removed. In case of any signs of cargo movement, the crew is called on alert to provide additional securing, using the appropriate securing materials and taking all precautionary measures, to wedge the displaced cargo items in the position in which they found themselves.

In accordance with the principles of sound seamanship and classification society recommendations developed for each vessel, 10% of the securing materials are set aside for emergency use by the crew at the port of loading after securing operations are completed. This reserve serves to reinforce deck cargo units during sea passage and is strategically located for ease of access. However, it should be noted that the exact amount of additional fasteners may vary depending on circumstances and the nature of the cargo - variables that have a significant impact on the safety of transportation.

3.Results and discussion

The transportation of deck cargo on seagoing ships involves solving a number of problems, analyzing the principles. These include the study of the nature of cargo shifting, elaboration of loading plan and stowage arrangements with the help of generalized conceptual model for organizing the deck cargo handling process, inertial forces considerations and calculation of scheme and securing systems which depend largely on many factors both on the type and technical characteristics of the vessel allocated for such cargo transportation. However, some problems are common for all ship types. First of all, it concerns voyage planning and development, determination of technology of deck cargo loading and unloading, strength calculation of ship structures, construction of supports and separation under cargo, but the main and key moment is control over vessel stability and trim alongside during cargo operations both by own cargo facilities and by shore-based facilities.

The provided bar chart on Figure 7, illustrates a comparative analysis of various safety measures pertinent to deck cargo management. Four key safety measures are evaluated: “Stowage Methods,” “Securing Techniques,” “Emergency Protocols,” and “Load Distribution.” Effectiveness scores, rated on a scale of 0 to 5, are assigned to each measure. The chart vividly portrays the relative effectiveness of these safety measures, offering valuable insights for optimizing deck cargo safety protocols. The higher the bar, the more effective the respective measure is perceived to be. This visual representation aids in making informed decisions regarding the implementation of safety strategies for deck cargo operations.

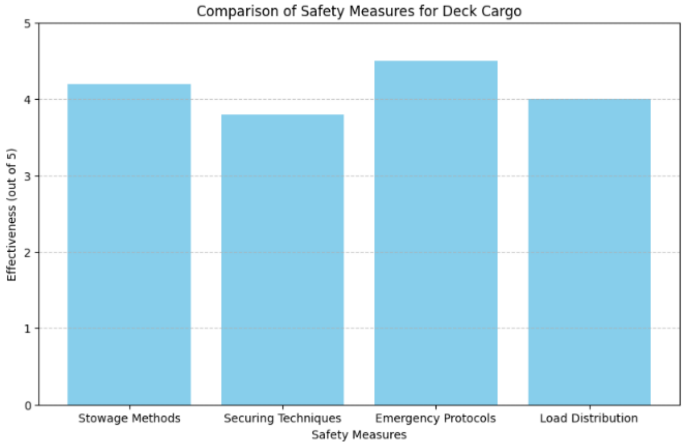

Figure 7: Safety measures comparison chart.

Therefore in order to summarizing the above mentioned factors and based on the generalized statistics of accidents with deck cargoes the dominating factors influencing the safety of handling and transportation of deck cargoes can be defined, and their consideration will help to minimize the indicators of damage and loss of deck cargoes in future (Table 2).

Table 2: Factors affecting the safety of the handling and transportation of deck cargo.

The process of loading deck cargo	Transportation process of deck cargo
1. Damage to the ship's structural elements and exceeding the strength limits of the ship's structures. 2.Creation of the emergency condition of shipboard cargo handling equipment as a result of inadequate loading;	1. Insufficient level of professional training and qualification of the crew; 2. Human factor through incorrect assessment of weather conditions. 3. Incompetent ship handling in stormy weather conditions

3. Breach of loading procedures and technology as well as codes and regulations for stowage and security of deck cargo; 4.Insufficient level of quantitative and qualitative characteristics of the dunnage materials and lashing materials; 5.Inadequate level of voyage planning, methods of monitoring the safety of navigation and scheduling the necessary measures to ensure the safety of deck cargo, its lashing, strength and stability of the ship during the entire voyage; 6. Neglect of weather forecasts while planning the voyage; 7. Absence of periodic ballast tank gauging and failure to perform pressurizing of the bottom tanks before the start of loading the deck cargo; 8.Loading of deck cargo with significant excessive height, in accordance with the Code of Safe Practice for Ships, when transporting deck cargoes; 9.Non follow up of deck cargo securing technique due to non-consideration of their mass-dimensional characteristics, which leads to increased costs of the securing process and increased number of workers, and increased time of the cargo operations; 10. Lack of conformity certificates of quality standards for the cargo lashing, securing and dunnage materials.	resulting in damage and destruction of the ship, damage or loss of deck cargo; 4. Lack of proper systematic supervision over the condition of lashing equipment during the voyage; 5. Absence of hydrometeorological support during the voyage; 6. Shifting of deck cargo due to breach of the procedure of stowage and securing of deck cargo, breach of the technology of cargo transportation under the influence of dynamic loads when the ship is sailing in stormy conditions; 7.Failure to take into account the requirements of existing regulatory documents on stowage and securing of the cargo and the methods of their calculation; 8.Not considering in full the transport characteristics and properties of the cargo, which have a significant impact on the safety of their transport; 9. Increasing risk of ship damage and loss due to the age and technical condition of the ship and the quality of its technical operation. 10. Inadequate calculation of the stability on departure and arrival of the ship and the absence of metacentric height verification by different methods; 11. Carrying out lashing in deviation from the standard requirements of the Regulations, absence of control over ship's stability during the voyage and absence of control over consumables;

The factors outlined in Table 2 are intricately connected to the elements listed in Table 1, which collectively influence the stability and safety of loading and transporting deck cargo. Here's a breakdown of how they interrelate:

1. Components of Weight (Table 1);

- *Center of Gravity Position*: The position of the center of gravity directly impacts the stability of the ship. If the center of gravity is not appropriately distributed, it can lead to instability during loading and transportation.
- *Transverse, Longitudinal, Lateral Stability*: These aspects are greatly influenced by the distribution of weight on the ship. Incorrect stowage of cargo may result in an uneven distribution, potentially leading to stability issues.

2. Components of Forces of Inertia (Table 1):

- *Roll, Pitch, Yaw Motion*: These motions are primarily influenced by the forces of inertia. Incorrect loading can alter these forces, potentially leading to unstable motion during the voyage.

3. Force of Wind Pressure (Table 1):

- *Heel Angle under Wind Load*: This directly relates to the force of wind pressure. If the cargo is not adequately secured or loaded, wind pressure can cause the ship to heel dangerously.
- *Sway and Lurch Motion due to Wind Forces*: These motions occur due to the forces of wind. If the cargo is not securely stowed, it may shift, exacerbating sway and lurch motions.

Regarding potential issues and risks:

- Improper Loading and Stowage can lead to an unstable distribution of weight and forces, increasing the risk of accidents or loss of cargo during transportation;
- Inadequate Lashing and Securing may result in cargo shifting, potentially causing dangerous movements of the ship;
- Failure to Consider Regulatory Requirements for stowage and securing can lead to non-compliance with safety standards, putting the vessel at risk;
- Neglecting Weather Conditions during voyage planning may lead to unexpected challenges and potential instability due to unforeseen weather events;
- Insufficient Crew Training and Competence can result in mistakes during the loading process, leading to safety hazards.

In summary, above described factors are directly related to the components in Table 1 and collectively affect the stability and safety of deck cargo operations. Proper consideration and adherence to safety protocols are paramount to mitigating potential risks and ensuring a safe voyage.

An ongoing discussion concerns liability in the case of such carriage. If the carrier agrees to carry the goods on deck without a special agreement in the contract of carriage or a clear indication in the bill of lading, it assumes liability for any damage to the deck cargo. Conversely, in the absence of a special agreement or indication in the bill of lading regarding the carriage of cargo on deck, consignees and bill of lading holders are governed by the Convention, placing all related obligations on the shipowner. It is important to note that a vague reference to the possibility of deck or non-deck carriage cannot be construed as a basis for assuming that the cargo is intended for deck carriage.

4. Conclusion

The model presented in the article is the author's development, which is based on long-term practical experience of this kind of transportation, scientific researches of the authors, including other studies of scientists. Practical approbation of the above algorithm was carried out during the transportation of deck cargoes, therefore the author's developments required theoretical substantiation, and thus only partially presented in this study, which opens for numerous researchers and practicing captains new facets of safe transportation of various types of cargoes, out-of-gauge cargoes and specific structured cargoes.

A comprehensive analysis of common causes of loss, damage and deterioration of deck cargoes, as well as a study of the regulatory framework, current documents and codes governing the stowage and securing of cargoes on board ships, has revealed a significant omission. It turned out that captains and crews do not fully take into account transportation characteristics and properties of modern general cargoes, both individual units and collective shipments. This omission significantly affects the safety of their transportation. The existing methodology of stowage and securing of deck cargoes does not allow to fully take into account the modern complexity and multicomponent nature of these cargoes, which sometimes hampers the availability and convenience of securing methods. This, in turn, leads to increased cost of lashing process, materials and labor-intensive lashing units, which ultimately delays loading and unloading operations. In this connection there is an urgent need to improve methods and techniques of fastening deck cargoes to ensure their safe sea transportation, as well as to assess their impact on the stability of the ship. The immediate tasks are to improve ship-handling technologies and to improve methods of cargo stowage and securing. This should be based on models that take into account possible risks and their consequences, which ultimately guarantees safety of navigation and optimizes the use of fasteners, especially in adverse weather conditions.

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