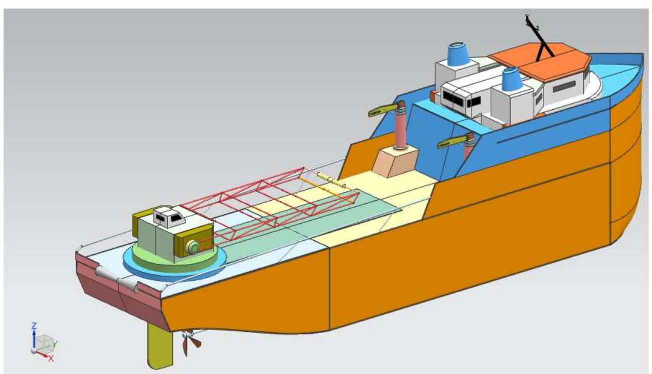
UNIVERSITATEA MARITIMĂ DIN CONSTANŢA
FACULTATEA DE ELECTROMECANICĂ NAVALĂ
ȘCOALA DOCTORALĂ DE INGINERIE MECANICĂ ȘI MECATRONICĂ

DOCTORAL THESIS

OPTIMISATION OF TOWING AND SAFETY EQUIPMENT ON BOARD AHTS VESSSELS



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INTRODUCTION

AHTS vessels have emerged at the same time as the maritime oil platform industry, and this field is constantly developing and presenting huge potential for the evolution of this sector, even today. These vessels are essential for the proper functioning of the aforementioned industry. AHTS is an acronym for "Anchor Handling Tug Supply Vessel", which means "vessel that handles the towing of drilling and production oil platforms, anchors for supporting these platforms, and last but not least, the supply of these marine platforms or other offshore installations."

This thesis is developed around three major research directions:

- Simulation using Siemens NX 12 software.
- Validation of numerical results based on experimental results obtained in the Applied Mechanical Engineering Laboratory.
- Analysis of results and development of future study directions.

Research in the Applied Mechanical Engineering Laboratory involved physically making test specimens at a scale of 1:10, which were subjected to strength tests using the GUNT WP310 machine in the same laboratory. The design of the test specimens was done in AutoCAD using the same scale. The measurement results obtained were close in value to those from numerical simulations, validating the results obtained using Siemens NX 12 software.

STRUCTURE AND MULTIDISCIPLINARY CHARACTER OF THE THESIS

The thesis is structured into four chapters, and the results presented have a multidisciplinary character, being both theoretical and practical. The conclusions obtained can have a significant impact on the evaluation of existing solutions as well as on the design of future generations of offshore installations. The studies focus on research areas related to offshore engineering, hydrodynamics of naval structures, as well as the development of the maritime energy exploitation field.

The practical research had the role of validating the results obtained through digital simulation, and the measurements obtained by the two methods were close in value. The paper presented the initial design and analysis of various elements belonging to AHTS vessels.

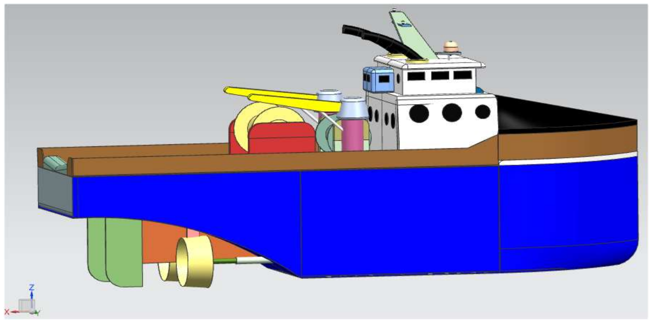
The aspects presented in this thesis ("OPTIMIZATION OF TRACTION AND SAFETY INSTALLATIONS OF AHTS VESSELS") facilitate a better understanding, as well as the possibilities of innovation, efficiency, and optimization of AHTS vessels. The research presented has a multidisciplinary character and can form the basis for the development of future projects with application in the field of offshore safety.

CURRENT SITUATION OF AHTS VESSELS

AHTS vessels have evolved with technological advances. Improvements and innovations have appeared in all aspects: the vessel's body, propulsion systems, onboard equipment, assistance installations, guidance, compensation, etc.

Most modifications and innovations have been made to the bow (the front part of the ship). These changes were imposed by the necessity of navigating the vessel in specific hostile environments, such as the North Sea, where waves and winds can reach impressive levels.

Thus, today we have bow types such as Bulbous Bow, X-Bow, or Axe Bow (which will be presented below).



The current AHTS vessels have at least two towing winches. This modification aims to streamline towing operations by better distributing forces and ensuring a higher degree of precision and redundancy. Today, safety is a top priority in shipbuilding, both for the crew and for the cargo. For this reason, the entire vessel is designed to withstand extreme conditions, especially high waves.

THE FUTURE OF AHTS SHIPS

The shipyards are already designing various versions of future AHTS vessels, which bring numerous innovations and optimizations both at the level of the ship's body and at the level of installations and equipment.

For the design of future AHTS-type vessels, it is necessary to know the general loads acting on the vessel under different operating conditions, thus allowing the determination of sectional efforts (shear forces and bending moments). For the studies carried out on the different structural elements that will be presented in the following pages, a high-quality steel with a density of 7.8e-06 Kg/m3 and a Young's modulus of 193000000 MPa was used. The yield strength of the material is set at ReH = 355 MPa, and the allowable von Mises equivalent stresses are σadm = 292 MPa. The finite element types of the 3D-FEM models are thick shell (Mandrin) elements with concentrated mass loads.

DESCRIPTION OF THE CONDUCTED RESEARCH

ANALYSIS OF STRESSES AT THE MAIN DRUM OF AN AHTS OFFSHORE SUPPORT VESSEL

GENERAL ASPECTS IN STRESS ANALYSIS

In this chapter, we will analyze a series of characteristic elements of the AHTS-type vessel, which is designed to carry out various operations in the offshore domain. Although this field is very diverse, AHTS vessels are specialized in the following types of activities: towing drilling and exploration oil rigs, transporting anchors for supporting these platforms, and last but not least, supplying these offshore marine platforms or other offshore facilities (Fig. 2.1).

The main specific elements related to the operation of an AHTS offshore vessel are: the crane (one or two), the traction installations, the drum (one or multiple), and the space for transporting various materials or platform anchors (the deck).

FINITE ELEMENT ANALYSIS OF THE MAIN DRUM

We have chosen to study the main drum as it represents an essential element in the entire traction system. Although there are various software programs available for stress analysis using finite element methods, we have chosen to continue using the Unigraphics NX program from Siemens.

The main parts that make up a drum are the drum body, drum discs, and drum shaft.

In practical applications, the drums are simultaneously subjected to both twisting and bending, which means that both normal stresses and tangential stresses occur.

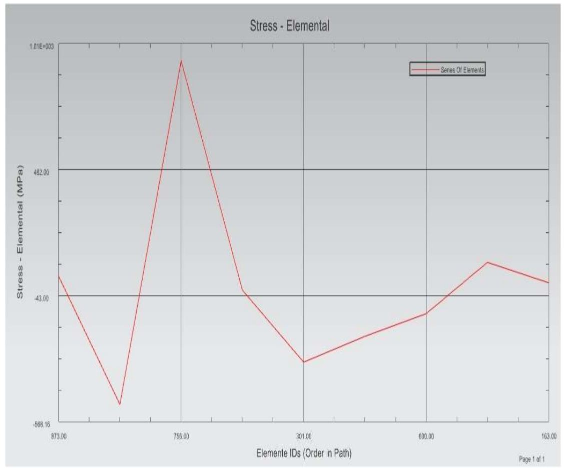
For drum bodies, it is considered that they are subjected to both bending moment (Mi) and torsional moment.

Next, we will study the importance of von Mises stresses (σv) for several practical cases of drums, since these stresses can occur both in bending and twisting simultaneously.

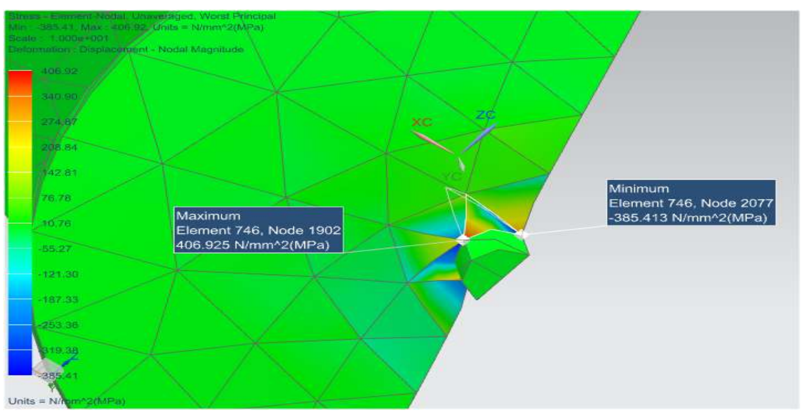
We have studied multiple cases using the finite element method to identify areas with potential risk of drum failure. Before determining the von Mises stress, we discretized the drum with finite elements of type CTETRA(10). Then, in all cases, we fixed the drum axis, applied a force resulting from the traction wire, and a bending moment.

Conclusions

After studying the six proposed versions of the drum, we concluded that the most promising ones in terms of resistance to deformation are cases two and six, as they have the lowest values of von Mises stresses (334.554 MPa and 339.913 MPa, respectively). From a theoretical point of view, the ring section represents the optimal solution compared to the circular section. The modulus of resistance of the ring section is higher than the modulus of resistance of the circular section, which means that the ring section can withstand a higher torsional moment (and the torsional moment is directly proportional to the modulus of resistance). The dangerous stresses have a maximum value of 406.925 MPa at element 746 node 1902 and a minimum negative value of -385.413 MPa at node 2077 of element 746. If at the beginning and end of the interval the values of the dangerous stresses are average, then in the middle of the interval the values of these stresses vary abruptly, which can lead to the idea of shearing at the lateral parts of the drum, followed by the rupture of this sub-assembly of the drum.



From a practical point of view, the most vulnerable area, i.e. the dangerous zone where the drum can easily break, is at the junction of the drum axis with its disc (Fig. 2.67). In conclusion, the most stable drum is the one in the second case with the recommendation that during maintenance of traction installations, the junction of the axis with the disc should be checked with an ultrasonic device, with great care. At this junction, there is a risk of internal stresses appearing that, due to the twisting and bending stresses to which the drum is subjected, can lead to plastic deformation or even breakage of the axis.



STUDY OF THE OPERATIONAL DECK OF AN AHTS SHIP

CURRENT ASPECTS OF THE OPERATIONAL DECK

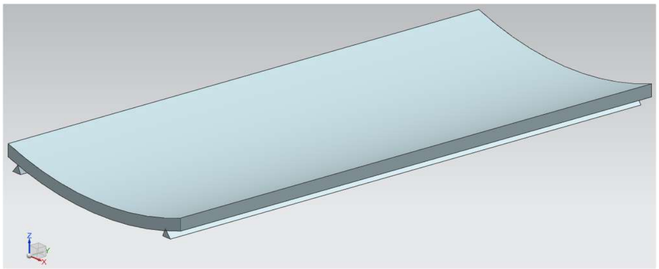
We will study the structure of the operational deck of an AHTS ship using the finite element method, using the same Siemens NX 12 program. To present an operational deck, we will choose a modern AHTS ship, highlighting the interest area.

As the activity carried out on the operational deck of the vessel by specialized personnel presents major risks, the use of safety cables tied to fixed structures is recommended, and it is also useful to use two sets of safety rails on each side. To guide the anchor chain, a set of cylinders is used to prevent excessive horizontal movement. One or more containers can be installed on the deck to store various materials and shackles used for anchor positioning.

Currently, a variety of systems are used for anchor launching. In the future, these systems will continue to develop as their speed and precision are essential to the safety of maritime platforms.

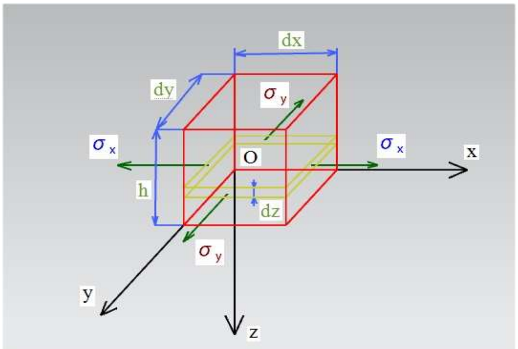
THEORETICAL STUDIES OF THE OPERATIONAL DECK

Since the operational deck is like a plate on which various heavy bodies (containers, anchors, etc.) are located, it is subjected to a series of efforts and stresses. To simplify the study, we will consider an operational deck as a flat plate. A flat plate is characterized by its length (L), width (l), and thickness (h). We will study the behavior of a flat plate subjected to cylindrical bending. A force uniformly distributed on the middle of the plate, represented by the anchor weighing approximately 20 tons, acts on the plate. The resultant of the force acting uniformly on the plate leads to a cylindrical bending of the plate.



Due to the cylindrical bending, by the moment M, the plate bends in the xOz plane, so that the plane passing through points c and d rotates over the plane passing through points a and b by an angle dθ, and finally the plane will pass through points c' and d'.

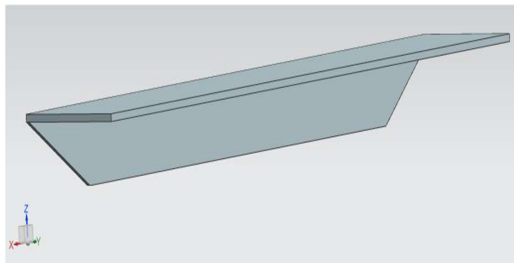
From this plate, an infinitesimal element in the shape of a parallelepiped with dimensions dx, dy, and h can be studied.



On the neutral element, a median surface is taken on which normal stresses σx and σy act. The thickness of this median plane is dz. If the bending moments Mx and My act on the plate, they will also act on the infinitesimal element (of volume) and consequently on the median surface.

ANALYSIS OF THE OPERATIONAL DECK USING THE FINITE ELEMENT METHOD

During this study, we decided to experiment only on a surface that represents half of the deck, at a smaller scale and with a simplified model. We performed discretization for each proposed variant separately.



In this efort, we highlighted the importance of operational decks as they are extremely important elements for this type of vessel. According to the conducted study, optimizing operational decks will lead to increased safety and reliability of AHTS vessels.

The results are presented in the “Conclusion” section.

OPTIMIZING CRANES FOR AHTS VESSELS

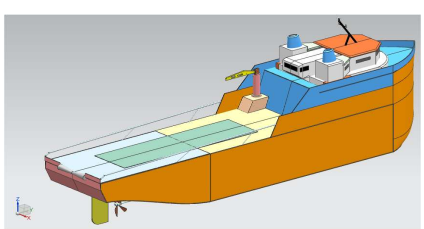
GENERAL ASPECTS IN CRANE OPTIMIZATION

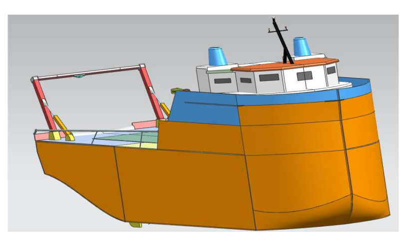
The first AHTS vessels represented an evolution of the classic PSV/OSV (Platform Supply Vessel/Offshore Supply Vessel) model, which was used to transport various facilities, supplies, and materials needed in the exploitation of offshore oil and gas sources. The first such devices materialized in the form of cranes.

CURRENT STATE OF CRANES FOR AHTS VESSELS

AHTS vessels, like other types of vessels (general cargo, fishing vessels, etc.), use various types of cranes in daily operations:

- Fixed automated crane, located on one of the vessel's sides;
- Two symmetrically arranged cranes;
- Heavy-duty crane;
- Cranes used to handle torpedo anchors;
- A pair of cranes, with independent operation from each other, to operate in parallel with a pair of fixed cranes;
- Crane with independent movement.





Usually, the cranes on deck are fully automated. In this regard, when working at a fixed point (dynamic positioning), they must automatically maintain their balance, compensating for all dynamic factors to which the vessel is subjected .

ANALYZING THE CRANE ARM USING FINITE ELEMENT METHOD

For the study of crane arms on AHTS vessels, we will use the finite element method, using the same NX 12 program from Siemens.

INTERPRETING RESULTS OF NUMERICAL CASES

After studying several cases of crane arms present on AHTS vessels, we concluded that the last case represents the optimal solution because it withstands various types of stresses and stresses well, presenting lower production costs compared to the other types studied and being relatively easy to achieve with current technology.

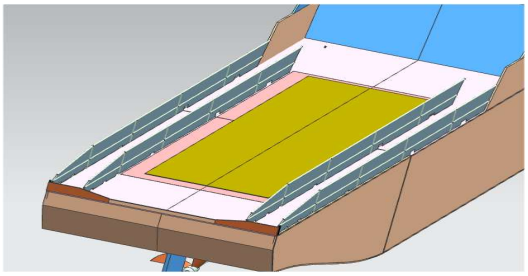
STUDYING SIDE WALLS FOR AHTS VESSELS

GENERAL ASPECTS IN CALCULATING THE SIDE WALLS OF THE DECK

The first constructive solutions for side walls were represented by simple steel plate sheets welded to the deck and between them, the strength obtained being limited. The next solutions adopted in designing side walls were based on the use of thin columns, on which sheet metal was welded. By adopting this solution, the possibility of water evacuation through the lower part of the assembly was created.

CURRENT STATE OF SIDE WALLS FOR AHTS VESSELS

The protective bars at the operational deck level can be simple or doubled to increase the safety of sailors, the vessel, goods, and installations present. Here is an example of a solution where the side walls made of protective bars and steel plates were doubled.



Bending is an important phenomenon that affects safety bars and plates, which are identified as flat plates in our case. The following assumptions are used to study the bending of bars:

1. The vertical plane xy, also known as the plane of forces, is a plane of symmetry of the bar.
2. The x-axis (straight line) is the axis of the undeformed bar.
3. The length of the bar is l and the height of the bar section is h.
4. Bernoulli's law is used.

5. Hooke's law is used for the material from which the safety system is made.

Conclusions

In this section, we aimed to study the most important models of towing and safety systems present on board AHTS vessels in their activity of assisting offshore platforms. According to the study results, in terms of strength, the difference between the three proposed models is not significant, and the solution adopted largely depends on the budgets allocated to manufacturing costs and the specificity of the requirements resulting from the operating conditions of the vessel. An interesting option would be to propose a solution with demountable side walls, as different elements and configurations can be used to maintain safety and efficiency on board depending on the location and operating conditions of the vessel. Therefore, at the end of the work, we will address a single model with demountable walls.

The conclusion of the study on safety systems for AHTS vessels suggests that the use of demountable walls is a viable solution due to their ease of installation and lower production costs compared to fixed walls. Further research can be conducted on the use and effectiveness of demountable walls in AHTS vessels.

❖

The next section discusses the principles of the tensile testing experiment, which is fundamental in material testing. The GUNT WP 310 hydraulic stand will be used for the experiment, which will explore concepts such as tensile strength, strain, elongation at rupture, and reduction of area. The tests will be both qualitative and quantitative, using various materials in 1:10 scale test specimens due to technical constraints. The results will be compared at the end of the experiment.

This device displays force and displacement digitally. The applied force is displayed with a positive sign in the case of tensile forces. The zero value of displacement corresponds to the lowest final position of the upper traverse. Exceeding the maximum permissible force (±50kN) is indicated by an audible warning signal. The measured values can be transferred to a PC through a USB interface available on the back of the device.

To define the general analysis element of the thesis, a simplified model was used based on the following assumptions:

1. In all cases, the test specimens and sections presented in Figures 2.200-2.220 have a constant thickness;
2. The stresses used in the analysis are limited to simple tensile and bending tests and their composite loading.

For the present study, a classic testing was adopted on the WP310 GUNT stand using 5 types of specimens made of the following materials: aluminum, ABS, plexiglass, fiberglass, and composite. A total of 20 specimens were tested successively to validate the results simulated in the thesis.

MODELING TEST SPECIMENS IN AUTOCAD

VALIDATION OF THE MODEL THROUGH MEASUREMENTS AND ANALYSIS OF RESULTS

According to current standards, the following mechanical characteristics are defined:

- the yield strength Re, which is represented by the stress at which the elongation of the specimen changes without an increase in force; the yield strength is calculated as the ratio of the force corresponding to yielding, Fc, and the initial cross-sectional area of the specimen, A0: Re = Fc / A0 [MPa]
- the proportionality limit (technical) Rp, which is represented by the stress corresponding to a prescribed residual strain. For steel alloys, a residual strain of 0.2% is accepted, in which case the technical yield strength is denoted by Rp0.2;
- the tensile strength Rm, which is defined by the ratio of the maximum force and the initial cross-sectional area of the specimen: Rm = Fmax / A0 [MPa];
- the elongation at fracture An, given by the relationship: An = 100 (Lu - L0) / L0 [%], (2.199) where L0 is the initial distance between the marks and Lu is the final distance between the marks, measured after fracture. The WP 310 stand is equipped with software that automatically plots force-strain and stress-strain curves. The graphs plotted by the researcher will be based on reading at least 10 points from the diagram and completing the table below for each test, as shown in the figure below.

Material	**Test 1 [kN]**	**Test 2 [kN]**	**Test 3 [kN]**	**Test 4 [kN]**	**Test 5 [kN]**	**Av. Value[kN]**
Aluminum	1.10	1.12	1.14	1.08	1.06	1.10
Composite	0.90	1.05	1.05	1.02	0.98	1.00
Fiberglass	1.2	1.15	1.25	1.05	1.10	1.15
ABS	1.41	1.42	1.40	1.41	1.41	1.41
Plexiglass	1.40	1.38	1.40	1.41	1.41	1.40

CONCLUSIONS

GENERAL CONCLUSIONS

The research carried out in this paper focused on the study of a series of characteristic elements of AHTS vessels, elements related to both safety in operation and reliability and efficiency. The data presented constitute a complex image regarding the use of Siemens NX and Abaqus type applications in the study of this type of ships. The thesis was structured into three chapters, an explanatory introduction that includes the objectives, structure, and multidisciplinary character, the content of the paper presenting the stress analysis, and in the last part remaining the conclusions and personal contributions. The results of the thesis have been disseminated in various scientific articles and publications, being also presented in prestigious events in the technical field.

ORIGINAL CONCLUSIONS

Engineering constructions have represented an important resource for the development of society as we know it today. The continuous development of these constructions, the search for new ways of study and analysis, is an essential condition for ensuring the perpetual evolution of new technologies and their application in day-to-day challenges. The current thesis focused its study on a less addressed field, namely that of AHTS vessels, and the optimization and streamlining of the specific installations on board of them, significantly depending on the good conduct of the offshore hydrocarbon extraction industry. Following the research conducted using theoretical aspects, numerical simulations, and validations through experimental methods, the following punctual conclusions resulted:

- The most stable drum is the one in the second case, with a constructive shape with a ring section of the drum, with the obligation that during the maintenance of the traction installations, the joint between the axis and the disc must be checked with an ultrasonic apparatus with great attention. In this joint, there is a risk of internal stresses that, due to the torsion and bending loads to which the drum is subjected, may lead to plastic deformation or even the breaking of the axis. The constructive form is the simplest and least costly to make and change in case of cracks, deformations or even breakage.
- According to the study, operational decks have increased safety as long as the level of transverse and longitudinal elements has a position and a number corresponding to the sampling resulting from the design calculations.
- Regarding the crane arms present on AHTS vessels, following the study of multiple proposed solutions, it results that the last case represents the optimal solution because it resists best to the various types of stresses to which the ship is subjected (e.g. storms, roll and pitch movements, etc.). Moreover, this type of arm has lower production costs compared to the other types studied.
- Regarding the strength of the side walls, the difference between the three proposed models is not substantial, and the solution adopted largely depends on the budgets allocated to manufacturing costs and the specific requirements resulting from the operating conditions of the ship. The use of demountable walls is a viable solution, as they are easy to install when needed and the production cost is lower compared to fixed walls. In the future, an in-depth study on the use and efficiency of demountable walls on AHTS-type ships may represent a new research direction.

As for the practical part of the thesis, the test results on the GUNT WP310 machine are close in value to those obtained from numerical simulations, validating the numerical results obtained using Siemens NX 12 software. Optionally, opportunities can be identified and new design solutions can be found for future AHTS ship projects using the research methods used in this paper. Based on the validated results in the Applied Mechanical Engineering Laboratory, any other operational situations on AHTS-type ships can be analyzed.

PERSONAL CONTRIBUTIONS AND FUTURE RESEARCH DIRECTIONS

PERSONAL CONTRIBUTIONS

The following are some of the significant elements included in this paper that represent personal contributions made:

1. Based on the specialized literature, a documentation of the current state of AHTS ships was conducted, as well as a brief history of these ships.
2. Modeling an old-type AHTS ship in the Siemens NX program, which served as the basis for all numerical simulations in this paper. All numerical simulations were conducted using the NX Nastran/Siemens program and the Abaqus program for very complex 3D-FEM models.
3. For the transposition of tensions that arise during various operations aboard the ship, the first stage involves analyzing the tensions at the main drum of the AHTS ship. Thus, 3D models were created for simulating various constructive drum cases. The analyses conducted on the drum present the results obtained in various situations for torsion and bending stresses. The following types of models were used for comparative study of the drums: a drum with a circular cross-section body, a drum with an annular cross-section body, a drum with an alternative version of its discs, a drum with a hyperbolic body shape, a narrow drum solution, and a narrow drum solution with an annular cross-section.
4. The next representative point of the paper is the study conducted on the operational deck of the ship, analyzing its behavior under the various forces generated by the presence of cargo and ensembles aboard the ship. For this point, several constructive variants were proposed, as follows: half of the operational deck with a longitudinal structure at the end representing the diametral plane, the entire operational deck with the structure of the longitudinal element represented in the diametral plane, the entire deck of the second model to which a transverse tie element was added on either side of the longitudinal element. The fourth model type is characterized by an increase in the number of ties compared to the previous one. The penultimate model proposed for analysis was a deck with a longitudinal element and three transverse resistance elements with provision for lightening holes. The last solution, which is also the most complex, is represented by a 3D-FEM model, namely a deck with three longitudinal elements, one main element represented in the diametral plane, and two symmetrical elements on each side as well as four transverse structural elements with lightening holes. The stress study of the first five models was conducted using the Siemens NX program, while the last one, which was dedicated to a much more complex model, was conducted using the Abaqus program.
5. Another point is represented by the optimization of cranes for AHTS ships. For these equipments, different constructive models have been tried, which were also analyzed with the help of the NX Siemens program. In the first proposed variants for study, square and rectangular tube-type profiles were used alternately. The third and fourth cases propose the insertion of circular and rectangular relief cutouts, respectively, along the entire length of the arm studied in the second case. The last two cases propose a complex geometry with a specific longitudinal section for the crane arms, the last case also proposing bordered relief cutouts to reduce the weight of the crane arm and ensure better resistance of its body.

6. Another aspect treated in the thesis is the calculation of the side walls or hull. In this case, a simplification of the model was used, using bar-type structures.
7. In addition, the resistance calculation of the structures that ensure safety at the level of the operations deck and protective bars was carried out. For the model of these bars, several constructive variants were proposed, such as: open, closed, or combined. The most favorable constructive variant was the last one presented in the respective subchapter, namely the model with bars mounted on the exterior face.
8. For a comparison of materials used in shipbuilding, experiments were carried out on specimens made of various materials for determining their behaviors and stresses at the level of the Applied Mechanical Engineering Laboratory within the "Mircea cel Batran" Naval Academy. In this chapter, the stresses on the specimens, elongation at breakage and deformations were studied, all of which made it possible to compare the results obtained on the stand with those from numerical simulations.
9. The research carried out in the thesis formed the basis for the realization of numerous scientific articles presented at national and international conferences.

PERSPECTIVES OF FURTHER DEVELOPMENT

In the future, the information resulting from the research conducted in this thesis can serve as a basis for optimization efforts, including:

1. NX analysis of requests for other types of ships and installations;
2. development of new theories and calculation models for testing and validation;
3. calculation of stresses for any loading conditions on board AHTS vessels.
4. identification of maximum tangential stresses.
5. calculation of dangerous stresses.
6. future study of the mobile drum solution for operational cases encountered on board AHTS vessels, as well as the evaluation of the feasibility of its installation on other types of ships.
7. generation of new study models with the help of NX Siemens for other installations, evaluation, and validation through the same laboratory procedure.
8. identification of new materials for the shipbuilding industry and development of new prototypes.
9. based on this work, we also propose to calculate the requests for a ship in equivalent quasi-static meeting-following waves for the equivalent beam model and the 3D-FEM model, as well as the navigation capabilities of the vessel, with proposals for combinations for different types of drums, cranes, and hulls among those presented in this thesis.