TRANSNAV
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 18
Number 1
March 2024

DOI: 10.12716/1001.18.01.05

Method for Determining Location of FSRU Terminal

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ABSTRACT: The article concerns the process of determining the safe location of the FSRU (floating storage regasification unit) terminal. The article introduces the process of analysis both in the context of navigation and manoeuvrability, as well as the process of analysing the movement of the ship's hull at the quay in order to determine the operability criteria of the terminal. The article indicates that in order to determine, a safe location for the FSRU terminal in the context of gas storage and regasification, many aspects should be analysed, in terms of weather, safe navigation, environmental and security conditions especially in present military situation i Europe. Therefore, a brief review of the type of FSRU terminals, the review input data for analyses, and the type of simulations to be carried out, also review of the current security situation in sea areas. The final result of the work will be create algorithm which will be as a help hand in process for safe selection the location of the FSRU terminal, as well it will be define a catalogue of anticipated risks in the sea areas, and indicate areas of particular sensitivity, i.e., what to put the most significant emphasis on to prepare for the occurrence of a given risk and what are the possibilities of reducing it to an acceptable level or even reversing the trend of increasing threats.

1 INTRODUCTION

Shipping is the driving force behind the global economy. The sea carries out nearly 90% of world trade. More than 60,000 sea-going vessels are transporting various goods (1 976 48 thousand DWT in 2019), passengers, and conducting offshore works navigating in the sea area [3,8,10,11]. Hence, ensuring safety in sea regions is a priority aspect of all sea users. Any disturbances in the functioning of the complex transport and organizational system may lead to various adverse effects, including threats on a global or local scale, the event of potentially dangerous situations, and even generate an economic crisis.[5] Diversification of LNG supply sources in the current global situation is one of the important goals for countries

The problem will be considered in terms of the appropriate choice of terminal location FSRU, taking into account the aspects of safe port manoeuvres as well as the availability and operability of the FSRU terminal.

In general, international maritime security concerns all beneficiaries of the seas and oceans; is the safety of life and property by protecting the marine environment against the undesirable effects of human activity. The result of which may be an incorrect selection of the location of the FSRU terminal, which may result in an environmental catastrophe, risk to the safety and security of the terminal itself and neighbouring areas, as well as failure to use the full potential of the investment. The international nature of maritime security means that when building regulations on maritime security issues, we must take into account already existing international concepts and procedures in such a way as to safeguard and take into account national interests. The maritime security of the state is a component of national security. It is a matter of national policy and strategy and safe interaction between land and sea users. [2,4,14]. Determining the appropriate location for the FSRU terminal where it will be safely operational for at least 97% of the time, a year (frequent requirements of investors) requires many simulations and technical analyses as well as analysis of regulations and legal requirements.

2 METHODOLOGY AND REVIEW OF THE SUBJECT LITERATURE

2.1 *The research problem*

The main research problem is the develop a algorithm aimed at providing tools for efficient determination of, a safe location and type of FSRU terminal, taking into account the hydro-meteorological conditions, existing infrastructure and the intensity of ship traffic in the area.

To achieve the main objective, it is worth breaking matters down into the following specific goals, the chronological implementation of which is discussed in the content of individual subsections of the paper. The basic research method used to achieve the aim of this paper is the analysis of source materials, scientific papers, carried out simulations on relevant simulators.

The collected data indicated areas of particular vulnerability to ensure safety in marine areas, where will be the terminal and implementation of effective preventive measures and response to increase availability and operability of the FSRU.

The general process of carrying out the investment construction of the FSRU terminal is shown on figure 1.

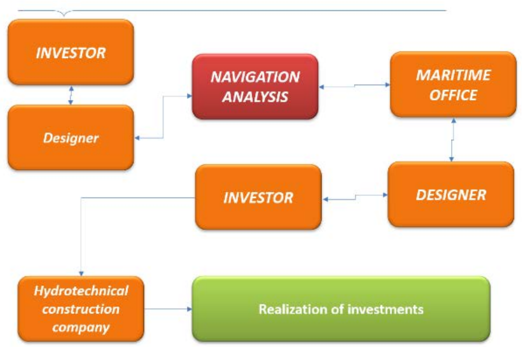


Figure 1. The process of carrying out the investment - construction of the FSRU terminal.
Source: Author elaboration

2.2 *Methodology of research*

The algorithm cannot be built without identifying of type of LNG terminals installed on the world. Depends to hydrometeorological and geotechnical conditions we can identify three general type of LNG terminals.

Important aspects is also identification of hazards and assessing the risk of their occurrence. This chapter is devoted to a reminder of the methodology for carrying out a risk assessment. Following the IMO resolution, indicators for the impact on the safety of human life and health, environment, and property protection of high value (in this case, a FSRU) have been implemented from its provisions. The foundation for further elaboration of the problem is to define the principles of risk index determination. It will be a reference point for additional modelling of the defined risks. This area's scope is dictated by the rationale of highlighting preventive actions before they could enter the "Not Acceptable" range. However, predicted risks might be challenging and not applicable in their occurrence due to the complexity and differentiation of the phenomenon from the previously assumed assumptions. [1].

To carry out the most effective risk assessment, it is important first to rank them. In this way, it is possible to understand whether the identified risk is minor or major. By taking this decision, one can achieve a more effective result, ultimately affecting the decision-making process. A crucial step for the success of the analysis process is to identify and prioritize scenarios for the problem under consider-action. This will allow prioritizing and rejecting scenarios that are considered to be of minor importance, and it will helps make decision regarding to localization and type of terminal LNG in considered localization.

2.3 *Types of FSRU terminals according to the mooring method*

FSRU is a floating storage regasification unit using for storage of liquid natural gas and also as distributor of natural gas after regasification process. FSRU usually is connected from one side to the shore gas transportation infrastructure and from other side to the LNGC by manifold with arms or cryogenic hoses. Figure 2 shows FSRU.

Figure 2. FSRU floating storage regasification unit.
Source:https://www.offshore-energy.biz/hongkong-lng-terminal-charters-mols-fsru-challenger [17]

There are three main methods of mooring FSRU and LNG carriers.

1. Side-by side jetty;
2. Cross jetty;

3. Weathervaning.

1. Side-by side jetty – FSRU is moored to the jetty and LNGC is moored double bank to FSRU. Advantages of the side by side jetty are:
   - low construction cost
   - simpler jetty
   - no LNGC directly alongside jetty

   Disadvantages:
   - longer mooring and unmooring operations
   - larger possibility of collision with moored FSRU
   - less operability criteria

   Figure 3 shows side-by side jetty.

Figure 3 Side-by side jetty.
Source: https://www.econnectenergy.com/solutions/lng/lng-terminal [15]

2. Cross jetty -FSRU is moored on one side of the jetty and LNGC is moored in opposite side of the jetty. Advantages of the cross jetty are:

- greater distance between jetty and breakwater,
- safer LNGC berthing (collision with FSRU eliminated),
- higher operability criteria,

Disadvantages:

- higher cost of construction
- larger dredging area

Figure 4 shows cross jetty.

Figure 4 Cross jetty.
Source:https://www.econnectenergy.com/solutions/lng/lng-terminal [15]

3. Weathervaning - FSRU is moored her bow to turret system. The Submerged Swivel and Yoke (SSY) is a cost-efficient system for mooring of a floating LNGC (FLNGC) vessel, floating storage and regasification unit (FSRU), or a floating storage and offloading (FSO) vessel in shallow water. The SSY provides an innovative solution, transporting gas directly through a subsea pipeline without the need for a jetty. SSY is based on APL's proven technology components and is designed to last for the field or terminal lifetime. The yoke weight is adjusted to the vessel size and environmental condition of the field or terminal. The system can be designed with dual risers and umbilical for redundancy and control on the pipeline end manifold. The SSY can be designed for disconnection in cyclone/hurricane environments without tug assistance.

   Figure 5 shows cross jetty.

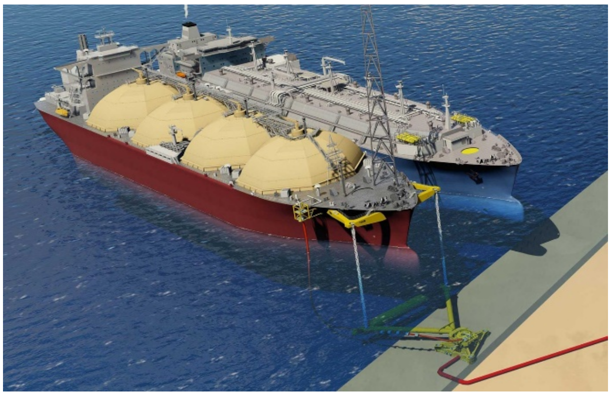


Figure 5 Weathervaning
Source: https://www.nov.com/products/submerged-swivel-and-yoke [14]

3 THE DETERMINATION OF USED SIMULATIONS

This chapter presents the navigational simulations in manoeuvrability aspects and ship hull motion study. For manoeuvrability simulations can be used full mission bridge navigational simulators. For ship motion study can be used CFD simulation with appropriate programs.

3.1 *CFD computational fluid dynamics 3D simulations*

The scope of ship motion analysis included examining the behaviour of the ships hull in the least favourable weather conditions. For the simulation, the least favourable directions of the hydro-meteorological conditions must be assumed. The simulations were carried out on the constructed digital simulation area, equipped with hydro technical structures (break weather, mooring dolphins, jetty shape). Scope of ship motion analyses covered simulation for FSRU 260.000m^3 stay alone, and with double banking with LNGC 175.000m^3 in two configuration for loading conditions (full loaded and ballast condition).The aim of ship motion analysis is to support availability jetty assessment, it can be done only when we will have knowledge about ship's hull movements in various weather and loading conditions. To achieve goal, results of ship motion movement simulations were compared with established jetty moored vessel criteria The CFD (computational fluid dynamics 3D) software utilized in the presented research was Flow Vision HPC (High-Performance Computing), which code is based on the finite volume method (FVM) and uses the VOF (volume of fluid) method for the free surface problems solutions. The simulations were performed using the overlapping mesh technique. The assumption of this approach is that one of the meshes is stationary in the whole computational domain, related to the global reference system. The second mesh modelling the ship is related to a local reference system, which movement is determined by six degrees of freedom (6DOF) model implemented into the program, with special consideration of three degrees of freedom (3D) – pitch, roll and heave. The high accuracy of computation is achieved by solving the governing equations in the 'free surface' cells (the cells partly filled with liquid). The simulations of turbulent flows were based on the eddy viscosity concept and k-ε semi-empirical turbulence model was applied. The practical application of the Flow Vision software is based on the consecutive steps performance. They are related to the geometry identification, modelling, pre-processing, solving the equations and post-processing (figure 6). The software "Flow vision HPC" and used methodology are suitable for ship motion response assessment.

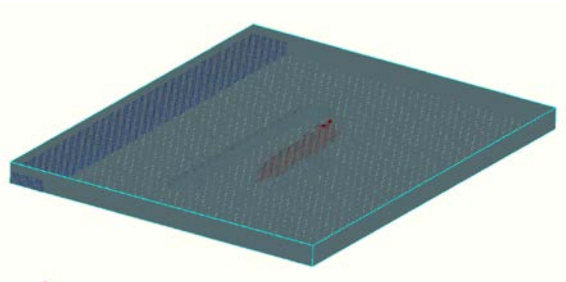


Figure 6 Computational grid - 10 million finite volumes, and adopted computational domain.
Source Author elaboration

To perform CFD numerical simulation for moored FSRU and LNGC, assumptions were made to changing the direction of waves, wind and current on the hull for moored ships. CFD simulation can be performed in various mooring configurations for moored ships in loaded and ballast conditions. Simulation performed for waves and winds from south, westerly, easterly and northerly directions are usually as a general. The direction and force of wind, wave and current, can be selected based on data from the Metocean database for interested area. Example of Metocean data shows figure 7.

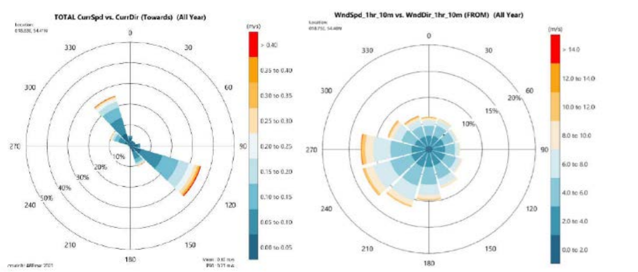


Figure 7 Current direction and speed, wind direction and speed, wave high and direction.
Source: Metocean data OF1-ABP-10-J00-RA-00002EN_Rev.2 [12]

3.1.1 *CFD simulation process*

By carrying out CFD numerical simulations for moored Q-max size using the adopted methodology and solver settings, solutions were obtained in the form of draft changes, considered as equivalent to vessel dynamic response motions at 4 points on the hull (figure 8) and wave distribution in the water area with assumed depth 14.5m. Figure 9 shows LNGC model used for CFD simulations.

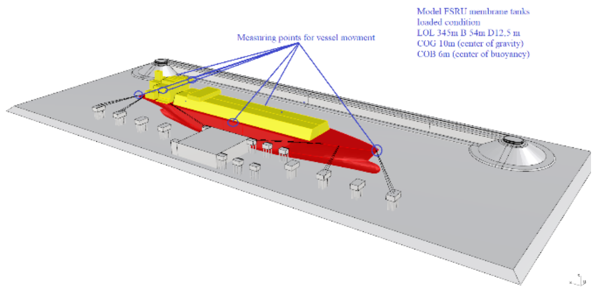


Figure 8 Draft reading points on the FSRU model hull.
Source: Author elaboration

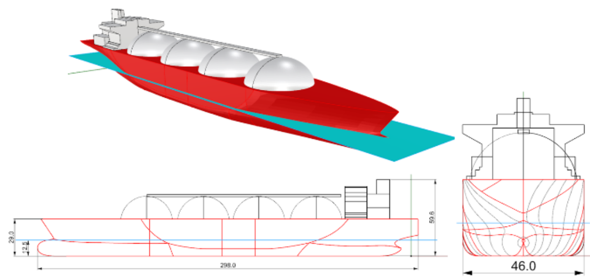


Figure 9 Model of LNGC used for CFD simulation.
Source: Author elaboration based on CFD database

Example CFD simulation for two vessels moored side by side, the following motion parameters had been observed: rolling, pitching, fwd draft, aft draft, heave, under keel clearance. The simulation results have shown that the hull motion for moored FSRU 260.000m^3 and LNGC 175.000m^3 caused by the Northerly wind 7-8°B, current and the wave adopted to simulation is within the accepted limits for hull movements. Distance between ships wings oscillates in the range between 3.3m-4.7m. Vertical movements for manifolds <1m. Simulations indicated that due to strong winds and waves from NNE direction increasing rolling for both vessels. LNGC in ballast is more sensitive for weather conditions and she has bigger rolling then FSRU, but still is on acceptable levels (rolling < 2°), however weather conditions reach adopted operability limits condition for terminal and it is recommended to stop cargo operation with LNGC (side by side/ wind limit 30kts , 15,4 m/s., hs=1.5m). Figure 10 shows wave process simulation and figure 11 shows hull movements parameters.

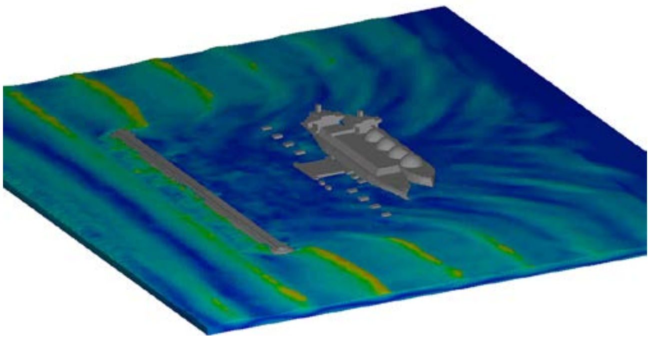


Figure 10 Wave system simulation.
Source: Author elaboration CFD simulations FSRU and LNGC

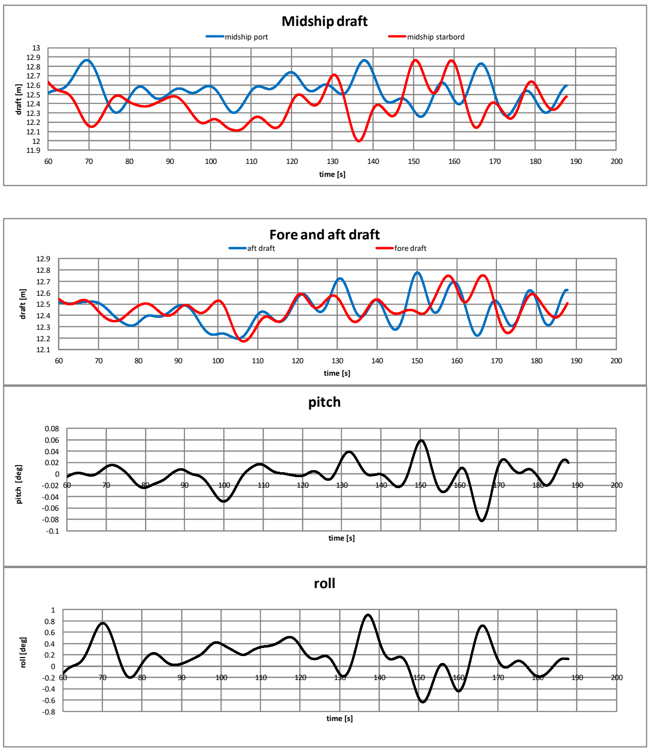


Figure 11 FSRU rolling and pitching caused by simulated waves.

In Table 1 had been show result for simulation CFD for hull movements for FSRU and LNG carrier double bank mooring.

Table 1. Results for CFD simulations

Simul.	Ship type				Pitching [°]		Rolling [°]		Draft FWD		Draft Midships [m]		Draft Aft		Heave [m]	Under keel clearance		Dist. between hulls		Compliance with adopted jetty moored vessel motion limits.
#	Ship	Size	Load cond	Loading Draft [m]	"+" FWD	"-" AFT	"+" STB	"-" PS	Max.	Min.	Max.	Min.	Max.	Min.		Min.	Max.	Min	Max	
5	FSRU	260 k	full load	12,50	0,06	0,080	0,90	-0,65	12,75	12,19	12,89	12,00	12,78	12,20	<1,0	1,61	2,00	3,30	4,70	Pass
5	LNGC	170 k	ballast	9,60	0,06	0,05	1,00	0,90	9,89	9,39	10,00	9,00	9,85	9,38	<1,0	4,50	5,50	3,30	4,70	Pass

Source: : Author elaboration CFD simulations FSRU and LNGC

3.2 *Navigational simulations – manoeuvrability*

The subject of navigational simulation studies was the implementation of approach and port manoeuvres with the selected LNGC model for the navigation basin on section of the fairway located on an approach to the newly planned FSRU terminal, in accordance to the scenarios provided by the Ordering Party. The aim of the research was to evaluate the performed manoeuvres by determining the safe trajectory of the ship, taking into account the adopted assumptions for selected environmental and operational parameters. The assessment is made in terms of the selection of the best location variant for the planned investment. The research was carried out on the basis of the simulation method. The use of a device based on extensive mathematical models made it possible to map the reactions of the ship and its surroundings in a manner similar to the phenomena observed in real conditions. Approach manoeuvres of ships on the fairway, taking into account the time in which the simulation takes place, were carried out on the basis of real time simulation (RTS) methods, using a non-autonomous model in terms of manage the ship's movement. Hydro-meteorological conditions in the measurement area, including the parameters of wind and waves, which are the main environmental factor influencing the correct course of port manoeuvres, were designed in accordance with the study provided by the contracting authority. The simulation tests were carried out with the use of a test stand located in the laboratory at the Faculty of Navigation at the Gdynia Maritime University. The measurements were performed with use of TRANSAS devices and software: NaviTrainer 5000 Professional navigation, manoeuvring simulator, NaviSailor 4000 ECDIS simulator as well as Model Wizard and Virtual Shipyard applications. The selected research stand has been used many times in scientific research, development and expert works. The simulator is used to conduct didactic classes at the operational and management level as well as specialist courses for bridge officers and captains. The most important regulations and standards met by the simulation software used:

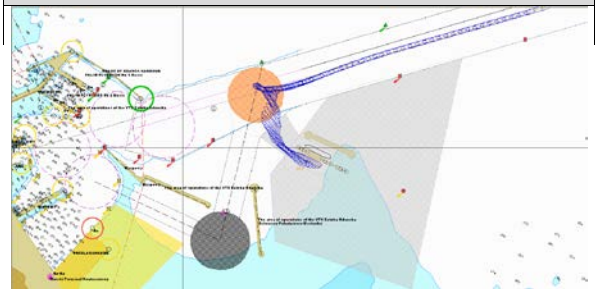
- International Convention on Training Requirements,
- seafarers, certification and watch keeping (STCW),
- The International Convention for the Safety of Life at Sea (SOLAS),
- Model courses to conduct specialist training courses by IMO,
- Additional regulations regarding specialist training, e.g. marine
- fishing operations and vessel traffic control (VTS) operators

The research consisted in carrying out the approach and port manoeuvres with the LNGC ship model for the fairway concept presented by the contracting authority. Measurement sessions were carried out according to standardized simulation scenarios, during which the following dynamic parameters of models and the environment were recorded in 1-second intervals in graphic and text form:

- simulation time,
- latitude (Lat.) and longitude (Lon.),
- actual course (HDT),
- road angle over the bottom (COG),
- speed above ground (SOG),
- longitudinal speed over the bottom,
- lateral speed (measured at the bow and stern of the vessel),
- the depth of the body of water (measured at the bow and stern of the vessel),
- rudder deflection,
- heel angle,
- pitching,
- wave height.

Example of manoeuvre simulation for cross jetty shows table 2.

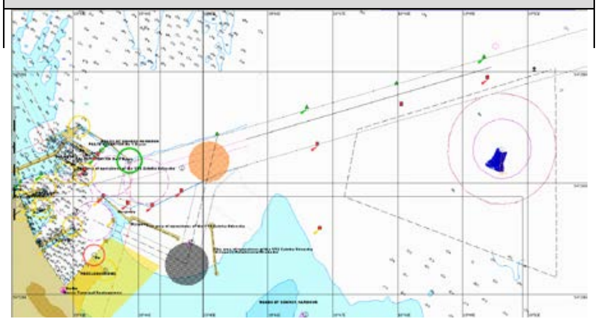
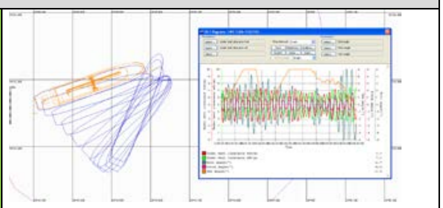
Table 2. Example simulation for maneuverer to cross jetty approach

Simulation no:	Approach 01
	Wind : „S" - 180° / 4-5°B / 16-21 kts
Weather conditions:	Surface current: 1 kt - 120° / Hs=1.5m
Model:	LNGC (260.000m3) – Loading condition draft 12.5m
Case Conditions:	Case 1,2,5,10,13 – Approaching from pilot station to LNG terminal "cross jetty" use of turning room at the fairway. Mooring STB/S alongside. 4 tugs connected.
simulation screenshot:	
	
Manoeuvre category:	Comments /conclusions:
Safe	From navigational point of view, the assessment of the trajectory of the approaching vessel, taking into account the adopted assumptions for selected environmental and operational parameters, showed that the simulation was classified as safe. When the manoeuvre was performing, no contact of the model with the seabed was recorded, no contact of the vessel with the hydro technical structure was noted, and the model remained within the set limits along the entire length of the fairway. Forces creating by wind, wave and current didn't disturb mooring operations, use of engines power was on acceptable safe levels with margin of power reserve.

Source: Author elaboration - approach simulation

Example of weathervaning simulation shows table 3.

Table 3. Example of weathervaning simulation

Simulation No:	Weathervaning 03
	Wind: NNE / 7-8°B/ 27-41 kts
Weather conditions:	Surface current: 1 kt direction according to wind and waves Hmax=6m
Model:	FSRU 260.000m3 loaded condition draft 12.5m.
Case Conditions:	Case 7 Weathervaning, at the "FB2 extended" position, Survival condition. Bow connected via Yoke system. **Depths at surrounding area 17,5m.** During test increase wind speed up to 41 kts, wave high 6 m. Wind and wave high according to operability criteria – limit for survival condition.
simulation screenshot:	
	
Maneuver category:	Comments /conclusions:
Aacceptable	
	A continuous time band with a nominal length of 01:00:00 [hh: mm: ss] was built, in which, for a given wave spectrum, wind speed and wave height constitute continuous non-decreasing functions. The parameters of the generated undulations were adopted in accordance with the provided "Metocean" study. Taking into account the adopted assumptions for selected environmental and operational parameters, showed that the simulation was classified as acceptable. When the simulation was performing, at depth area with 17.5m no contact of the model with the seabed was recorded. Forces creating by wind, wave and current generate following motion parameters : Under keel clearance FWD 3.3m

Source: Author elaboration – weathervaning simulation

4 RESEARCH RESULTS

The analysis of the results of the simulations carried out and the determination of best location of terminal, operating limits and availability of a given terminal in the tested lo-cations can be carried out when followed analyses have been performed: Use of data from hydrometeorological analysis

- Cumulative results from CFD simulations
- Accumulation of results from manoeuvring simulations
- Analysis of ship traffic intensity in a given area
- Analysis of scenarios related to the orientation of the berth and options for reloading gas on the LNGC - FSRU

When performing analytical research regarding the selection of a safe location for the FSRU terminal, the algorithm should have following steps:

- perform navigational analysis;
- perform analysis of hydrometeorological conditions in a given basin;
- perform analysis of ship traffic intensity in a given basin;
- perform analysis of scenarios related to the orientation of the berth and options for reloading gas on the LNGC - FSRU line;
- perform CFD (Computational Fluid Dynamics) analysis of the impact of hydrometeorological conditions on the hull of the moored FSRU and LNGC in various loading conditions;
- perform analysis of simulations of approach manoeuvres, mooring and unmooring operations;
- perform environmental analysis;
- perform security analysis
- perform analysis of current regulations, ordinances and guidelines.

Creating a risk matrix in order to select a safe location of the FSRU terminal on the basis of a summary of simulation results and the final determination of the operational and accessibility parameters of the terminal allows for the selection of the most advantageous of the proposed variants of terminal location.

The use of the proposed tools/methods translates into cost reduction and improvement of the facility's functioning both for the client's investor and the user.

An important aspect is also the identification of a sensitive area that may indicate a reduction in environmental degradation during the operation of the LNGC-FSRU terminal

Increasing the ability to detect/avoid collisions and, in the event of an incident, react quickly and appropriately to the threat in order to reduce the negative effects of e.g. a collision. The author is aware that this will involve legislative action and the introduction of security procedures. These activities may be extended over time and multifaceted, but as a result they are to reduce the number of threats to human life and health and the natural (marine) environment during the operation of the terminal. The current situation is starting to force such an approach to standardization procedures affecting a high level of safety during reloading operations

5 DISCUSSION

The presented approach to the selection of the appropriate location for the FSRU terminal indicates a multi-faceted nature. Simulations help in conducting in depth analyses and, as a result, in making the right decisions. Failure to use the modern potential of simulation techniques may result in incorrect determination of the location and thus increase the risk of an accident.

The major predicted risks to human life and/or health include:
– Risk associated with the intensity of unpredictable hydro-meteorological phenomena.
– Risks associated with the influence of natural hazards;
– Risk related to difficulties in rescue operations through the size of the vessels and number of people on board, and lack of adequate rescue measures;

The major predicted risks to the natural (marine) environment include:
– Risk associated with the intensity of degradation virgin areas unpredictable hydro-meteorological phenomena;
– Risks associated with the increasing numbers of death zones in marine areas;
– Risk related to difficulties in rescue operations through the multipurpose of degradations;
– Risk related to human health and property.
– Risk related to increase of high insurances.

The current state of affairs suggests the justifiability of preparing hazard scenarios for the possibility of introducing:
– Effective anticipation of natural phenomena;
– Early warning of natural phenomena;
– Strengthening the awareness of the phenomena occurring for the population, reducing the coastline as well as for those working in the maritime areas[6,7];

It is reasonable to consider the broadly understood integration of the possibilities of cooperation of different means and forces in the resulting potential emergency and the possible hazards.

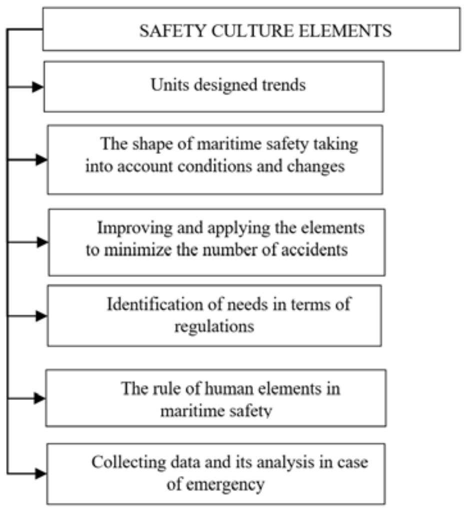


Figure 12. The elements shaping a Safety Culture.
Source: Own elaboration supported by:[9,10,6]

The authors hope that the discussion generated by the article and the attempt to provide a global approach to the process of determining the location of not only the FSRU terminal but also other terminals. This should be incorporated as decision support at every stage of ensuring safety in maritime areas during peace time or crisis. Safety culture elements shows figure 12.

6 CONCLUSION AND SUMMARY

The research shows that, despite the use of various means, there is a threat to life, human health and the natural environment when the determination of the appropriate location for a given terminal is incorrect. The risk of error can be reduced by all possible means. The main purpose of the work was to develop a scheme/algorithm for the correct determination of the location of the FSRU terminal in offshore areas. The conducted research showed a wide spectrum of issues. Breaking it down into specific simulations allowed it to be classified in a specific way and indicated the multidimensionality of its components. According to the author, during the research, numerous problems were encountered in access to literature and the multidimensionality of the issue, but the goal was achieved. Undoubtedly, a real threat is the uneven development of advanced solutions, technologies, integration of systems with the assessment of potential threats.

There is still much work to be done to reduce errors and improve simulation accuracy. The decision-making process, the creation of a risk matrix while considering many aspects and factors taken into account in determining the correctness of the terminal location and its arrangement as well as the hydrotechnical infrastructure is a multidimensional process. It can even be said that the completion of one analysis process is the beginning of preparations for subsequent analyses. Further development of the subject will undoubtedly become the subject of the author's subsequent studies.

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