Analyzing of risks during tanker operations at off-shore terminals

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Abstract: - Today, more than other times, safety is the first care in all maritime operations. On the other way, maritime operations can be divided in low awareness and high awareness regarding safety. For the first, the safety operations are give it by the nature of cargo operated or by the operational devices and procedures used for this. In the second group are meet cargoes which request high attention during their operation. In this category we include dangerous cargo, liquid chemicals, liquid gas, oil and petroleum products and other cargoes which present risks in their operation. In the same time, many of these cargo are started to be operated inside of external harbors terminals, where is consider to present a lower danger in case of any abnormal operational situation, or, due to possibility to increase the operational ratio in order to increase the final operated quantity. Starting from these considerations, in the present paper, we will try to present the risks possible to appears during operation of oil tankers in off-shore terminals, especially those determinates by the environmental factors impact on ship and terminal during operation, in particular when ship mooring lines are broken and ship are exposed to grounding risk.

Key-Words: - Oil carriage, VLCC ship, off-shore operation, safety, mooring lines failure, risk

1 Introduction

In actual context of oil and natural gases exchange, an important element is represented by the carriers. The oil carriage is covered in this moment by maritime transportation in a proportion of 62%, the other 38% being mainly carried by pipe lines with a large development in Europe, Russia and United States, in connection through Canada and Alaska. By the sea, the biggest oil quantities are carried from Persian Gulf to Europe, South-East Asia and North America.

The world tanker fleet (without ships used for military carrier purpose), in year 2007, represent a transported quantity of around 280 million tons. At this time, over 3,500 ships are involved in oil carriage only. From these, 35% are tankers from VLCC category or bigger.[4]

For different trade relationships are used different ships with different load capacities with the main option criteria represented by the distance to be covered and both ends port operation facilities. The VLCC’s are preferable in oil carriage, especially for routes between Middle East to South East Asia and Europe.

The use of large tanker ships has advantage of quantity carried, but also the disadvantage of special logistics necessary for operation of these ships. To satisfy the own necessity, bigger consumer countries developed the necessary logistics in the same time with quantity increasing. In this way have appeared specialized terminals for large tanker ship operation, inside of existing ports, or have been built new terminals for these ships operation.

Where the improvement of the port structure couldn’t be changed to satisfy the operational request for large ships, has been chosen to outward these operations, to build new off-shore terminals. The advantage of this type of terminal is given by the possibility to operate ships with different tonnage and to assure a higher product transfer rate.

Increasing of oil quantity carried by sea and development of terminals able to operate these ships
have generated in the oil maritime industry new challenges, mainly related to assurance of a safety working environment, and improvement of procedures and actions in case of any malfunction in operation.

Taking in consideration oil quantities carried by a very large tanker ship, first care was to prevent accidentally pollution during operation at off-shore terminals. In this case, pollution can be generate by the ship tanks overflow, situation very probably to be met due to ship movement under action of environment elements like wind and waves.

Other preoccupations about safety of operation are about the possibility of any collision between the tanker under operation and another ship, collision between tanker and operational buoy, possibility of cargo transfer equipment failure or damage by the ship during her movement, failure of ship mooring lines in rough sea condition, ship departure from terminal after mooring lines failure and grounding.

All of these considerations have been taken only about ship operation process, beside others related to security aspects during tanker ship operation at off-shore terminals.

To analyze what happen in case of any failure of mooring lines during loading operation and in rough sea conditions, we use mathematical models for ship movement and wind and wave modeling, together with simulated applications for a real image of this situation.

For analyzed situation was considered a VLCC tanker ship under loading operations at a mono-buoy terminal.

2 Oil tanker operation at off-shore terminals

Due to increasing oil and oil-derived products carriage on sea and the appearance of supertanker ships, the number of ports able to satisfy the operational requests has been reduced considerably. These facts led to the conception and building of open sea terminals, called sea-berths, where operation of supertankers can be done without any impediments.

Beside advantages give it by possibility to operate ships from supertanker class, the off-shore oil terminals offers also a high grade of security in operation, taking account that any kind of threat is hardly to be put in fact in this condition. Also, in case of a dangerous situation, no other areas will be affects.

To realize these considerations about operation capacity and safety and security was developed a number of off-shore terminals, each of them with advantages and disadvantages, like are presents below.

The off-shore terminals, as general structure, are special hydro technical constructions, which allow berthing and operation of large tankers, using more mooring buoys, only one special mooring buoy or a single fixed point mooring.

The most used off-shore system is the mono-buoy mooring system, used in ports areas, extraction field and also in case of oil transfer near a marine drill platform. This type of terminal consists in a special design buoy, anchored with 4 to 6 anchors or fixed with pillows strong implanted in the sea bottom. This buoy is placed in deep sea areas and allows mooring of large tanker without tugs assistance needs.[4]

An important disadvantage of this terminal is given by the risk of serious damages of the buoy due to contact with the ship during operation and especially during ship approach maneuverings.

Similar to the first one it has been developed the system with only one anchor, single anchor leg mooring. In this case, the buoy has the only scope of ship mooring, the transfer lines being placed under the ship keel of the largest ship operate in the terminal. This design avoids the situation of transfer lines damage in case of ship getting into contact with the buoy. [4]

In case of contact between ship and mooring buoy, only the buoy is affected without implications on oil transfer structure.

Any type of terminal is used have own advantages and disadvantages. In the line of safety is important to assure that in all operational situations, ship, terminal and environment are protected.

For these reasons today there are a number of procedures develop to increase the safety in operation at this types of terminals and to reduce the risks.[3]

In the present paper we will consider the tanker ship under operation at a mono-buoy single anchor leg mooring terminal. According with the terminal structure and arrangement, main risks are represents by the possibility of collision between ship and buoy, collision between ship under operation and other ship, fire onboard, failure of ship mooring line in case of rough sea and tear up of buoy anchor due to force exercise by ship movement.

Following to these primary risks there are associate risks like ship hull damage after collision with leakage of oil, grounding or heavy ship roll with oil pollution due tanks overflow.

Analyze is made to deduce the risks arise from a mooring lines failure during operation when the
tanker is in a loading condition other than ballast or fully load.

3 Mathematical considerations about ship behavior and environmental factors impact

In order to see how different state of sea influences the operation and ship-terminal safety we start our approach through mathematical considerations about forces and moments of forces which affects the ship and the buoy also.

Another important mathematical model is about the impact of environmental factors, like wind and waves, expresses through their forces and generated moments of forces.[1]

The equations terms represents the internal and external forces and moments applied on ship, like: inertial forces and moments, buoyancy force, ship weight, longitudinal and transversal restoring moments, hydrodynamic forces and moments on ship hull, wind, wave and currents forces and moments and additional, forces and moments generated by the ship-buoy complex.

Ship motion equations are:

\[
\begin{align*}
(m + m_1) \frac{dV_x}{dt} &= -(m + m_{22})V_x \omega_z + (m + m_{33})\omega_y V_y \\
(m + m_{22}) \frac{dV_z}{dt} &= (m + m_{11})V_z \omega_x - (m + m_{33})\omega_y V_y \\
(m + m_{33}) \frac{dV_y}{dt} &= (m + m_{11})V_z \omega_x - (m + m_{22})V_y \\
\end{align*}
\]

(1)

\[
\begin{align*}
J_x \frac{d\omega_x}{dt} + \left[(J_x + m_{66}) - (J_y + m_{55})\right] \omega_y \omega_z + \\
+ (m_{33} - m_{22}) V_y V_z &= M_x \\
J_y \frac{d\omega_y}{dt} + \left[(J_y + m_{44}) - (J_z + m_{55})\right] \omega_x \omega_z + \\
+ (m_{11} - m_{33}) V_x V_z &= M_y \\
J_z \frac{d\omega_z}{dt} + \left[(J_z + m_{55}) - (J_x + m_{66})\right] \omega_x \omega_y + \\
+ (m_{22} - m_{11}) V_x V_y &= M_z
\end{align*}
\]

(4)

where: \( \omega_x, \omega_y, \omega_z \) = angular velocity on correspondent axes, \( m_{ij} \) = added masses and inertial moments of the water on correspondent axes, \( F_x, F_y, F_z \) = on ship acting forces amount on correspondent axes, \( V_x, V_y, V_z \) = velocity components on correspondent axes, \( \omega_{x}, \omega_{y}, \omega_{z} \) = angular velocity on correspondent axes and \( M_x, M_y, M_z \) = forces moments amount on correspondent axes.

The restoring moments for ship longitudinal and transverse inclination produce by the weights moving onboard are:

\[
M_\theta = -m \cdot g \cdot h_\theta \cdot \Delta + M_{66}L
\]

(7)

\[
M_\psi = -m \cdot g \cdot h_\psi \cdot \psi + M_{66}L
\]

(8)

Longitudinal and transverse restoring moments are directly dependent on the ship’s load grade and cargo quantity moved from a side to other, an important influence being represented by the cargo tanks free surfaces.

To have a complete image of tanker ships behavior under operation at off-shore terminals it must be taken into calculation the influence of wind, waves and currents, most important firsts, because of the risks raised from their action. Principal risks determined by the wind and waves as wind action results, are represented by the tensions in mooring lines and ship moving around operational buoy with the possibility to affect connection pipes.[1]

In the present paper, the wind is considered as uniform flow around the ship with constant direction and velocity. The true wind velocity is average velocity value at 6 meters height from sea surface and is expressed by Beaufort number, according with the same named scale.

Aerodynamic forces and moment on ship hull are expressed as longitudinal and transverse components, using relations like:

\[
F_{x,t} = [C_{x,t}(\varphi_{\psi}) + dC_{x,t}(\varphi_{\psi}, \Delta_{t})] \frac{1}{2} \rho_{0} V_x^3 (A + A_{t})
\]

(9)

\[
F_{y,t} = [C_{y,t}(\varphi_{\psi}) + dC_{y,t}(\varphi_{\psi}, \Delta_{t})] \frac{1}{2} \rho_{0} V_y^3 (A + A_{t})
\]

(10)

\[
M_{t,t} = [C_{z,t}(\varphi_{\psi}) + dC_{z,t}(\varphi_{\psi}, \Delta_{t})] \frac{1}{2} \rho_{0} V_z (A + A_{t}) \cdot L
\]

(11)

where: \( V_x, V_y, V_z \) = wind relative velocity on ship, \( \varphi_{\psi} \) = relative wind direction and \( C_{x,t} \) = non-dimension aerodynamic coefficient

Wind relative velocity from previous relations has expression:

\[
V_{x,t} = \sqrt{V_{x,t}^2 + V_{y,t}^2}
\]

(12)

and relative wind direction:

\[
\varphi_{\psi} = \arctg\left(\frac{V_x + V_{y,t}}{V_z + V_{y,t}}\right)
\]

(13)

Sea rough model used can be represented as a super positioning of simple sinusoidal components with different amplitudes, frequencies and directions, according with following relation:

\[
f(x, y, t) = \int dA(\omega, \chi, t) \cdot \cos X
\]

(14)
where:
\[
\cos \chi = \cos(kx \cos \chi + ky \sin \chi - \omega t + \delta(\omega, \chi))
\]

Wave spectrum is considered function of frequency and wave direction and integrating on wave moving direction will result the frequency or point spectrum as:
\[
S_f(\omega) = \frac{1}{\pi} \int_{-\pi}^{\pi} S_f(\omega, \chi) d\chi
\]

An important aspect during operation at off-shore terminals is represent by wave height function of wave formation average period, so:
\[
3.2 H_r^{0.5} < T_f < 3.6 H_r^{0.5}
\]
where: \(H_r\) = referent wave height.

Wave referent height is determined to be equally with 1/n of a maximum wave height, usually taking n=3 and referent wave height resulted is \(H_{1/3}\).

To be able to determine wind and wave influences on ship-buoy complex, there must be known the forces produced by these in the complex components, like tensions in mooring lines and tensions in buoy anchor chain.

Force on mooring line is calculated using formula:
\[
F_{ml} = k_f \cdot \varepsilon
\]
where: \(\varepsilon\) = elongation and depends by the line length.

As a general rule, force determined with relation (18) must be always less as value than the breaking force value characteristics to each type of line used.

Force generated in the buoy anchor chain must be always smaller than anchor tear force.

4 Study of mooring lines failure risks using simulation technique

In order to see exactly what happens during operation of large tanker ship at off-shore terminals and to determine dangerous situations that can appear, we have introduced real environmental data in a simulation program and have analyzed the results.[2]

For this operation it has been chosen a double hull tanker ship characterized by the following particularities [2]:
LOA: 318.62 meters
Beam: 52.00 meters
Draft: 21.11 meters
Displacement: 246,302 tons
Deadweight: 209,997 tons

In normal loading/unloading conditions ship position in terminal is with the fore part to the open sea, like in Figure 1.

The off-shore terminal was considered to be positioned at 12 nautical miles by Constanta harbor entrance limit, out of ship anchorage area and without any interference with ship recommended routes from south to north or east to west. This position is characterized by depths of 40 to 50 meters, sand bottom and without protection against dominated winds.[2]

For ship mooring were used polyester lines of 70 meters length characterized by a breaking force of 882 kN and extensibility factor of 12%.

This type of mooring line is considered as usually used for tanker off-shore operation.

For our study the tanker was considered loaded in a percent of 50% of capacity.

Ship behavior was study for two sea rough conditions, characterized by wind speed and waves height. In the first case wind speed was considered of 10 m/s and waves with 2.0 meters height, in the second case, wind of 14 m/s and waves of 2.5 meters height.

Wind direction is 030 degrees.

For the first case, ship behavior was characterized by a rotation movement around the buoy, like in Figure 2, marked by higher tensions in the mooring line during consecutive positions number 5 to 10.
As results from ship movement analyze under action of a wind of 10 m/s speed and waves of 2.0 meters height, the tensions in the mooring lines don’t take over the maximum strength value of 885 kN and allow to the ship to keep position in terminal.

For the second condition, due to increasing of wind speed and waves heights, the lines failure value had reached and ship left the position in terminal.

According with ship consecutive positions under wind and waves action, the failure moments of mooring lines are position 5 for portside line and position 6 for starboard line, like is shown in Figure 3.

The risks possible in this situation can be group in two categories, according with the ship condition as: ship has the engine ready to use or engine are not ready or a malfunction has occurs.

For the first stage any risk is minimum, because has possibility to maintain a relative position near terminal using own propulsion capacity or has possibility to go to open sea area or inside of harbor protected area.

If the ship doesn’t has capacity to maneuver with own propulsion due an engine malfunction or engine start failure, then, the risks increase proportionally with the period necessary for fixing of these problems.

In this situation, after broken of mooring lines, the ship movement will be designed by the wind and waves direction, like is shown in Figure 4.

Analyzing the ship movement direction after mooring lines failure we have considered that grounding is produced after two, maximum three hours of drifting.

The grounding point will be situated south by the terminal position, in an area with a sandy bottom.

Taking these facts in consideration, especially the sea bottom nature and ship building as double hull type, the risk of hull damage with affecting of cargo tanks is less probable. Any leakage of oil from cargo tanks will be possible to be produce only due to ship high hell angle and lost of oil through overflow devices.

In case of hull serious damage with cargo tanks affectation, the oil quantity possible to be lost can be great. At 50% capacity load, inside of cargo tanks will be a quantity of around 100,000 tons of oil.

Pollution with such a great quantity of oil will affect all southern part of Romanian coast, the entire Bulgarian coast and in the same time, the entire Black Sea coast of Turkey.

The impact on economical activities like fishing industry, aqua cultures and coastal resorts will be disastrous.
The impact of a oil pollution in this case will be amplified by the sea rough which will accelerate the extending of oil spill on a large surface.

Costs for cleaning after such an accident will be great and time need for cleaning will be long. For example, for cleaning of oil spill after grounding of 37,000 tons tanker “Exxon Valdez”, in 1989, was necessary more than five years.

If the ship grounding will be produce without affecting of cargo tanks, and without oil pollution, the bigger problem will be represents by the refloating operations. These operations will be difficult to be done due to ship dimensions.

For both situations, the risks of mooring lines failure are great and suppose high costs after for fixing of problems generated.

5 Conclusion

Building of off-shore terminals for oil tankers means, in the first time, special measures regarding safety and security of operations. In off-shore operation conditions the ship is totally expose to environmental factors actions, which can be more dangerous than situation when ship is berthed inside of harbor area.

During operation at off-shore terminals ship position is assure by the mooring lines and strength of operation buoy anchor chain. Both elements are vital for safety of operation in any weather conditions. From both of these the anchor chain strength is cover through construction and by the use of heavy chains and fixed anchors.

The problem of mooring lines strength must be treats according with operation conditions and ship particulars.

As a general practice, the mooring lines used for tanker berthing are made from synthetic materials like polyester, polypropylene, aramid or dyneema. Each of these types of lines is characterize by different strength and elongation.

To appreciate the risks possible to appear during off-shore operation of very large tanker ship, we study ship behavior during loading process and under action of environmental factors like wind and waves.

Taking in consideration that ship use polyester lines for berthing and loading is made in presence of a 10 to 14 m/s speed and waves of 2.0 to 2.5 meters height, we analyze the risks for ship in these conditions.

At a wind of 10 m/s speed associate with waves of 2.0 meters height, ship behavior is normal, ship movement in relation with operational buoy being a rotation movement of around 45 degrees.

When wind speed is increase the situation is changed radically. At 14 m/s wind speed, the lines are broken and ship is totally exposed to wind and waves action.

For both ship condition considered, with or without own propulsion, the new created situation is dangerous. Most dangerous is the situation when ship doesn’t have capacity to maneuver because engine malfunction or starting failure.

In this situation, because of wind and waves direction, the ship will ground.

The ship grounding can result in huge oil pollution, if cargo tanks are damaged, or in a simple grounding only.

To prevent these risky conditions must be taken strong safety measures for operation, consists in study of weather conditions for all period of ship staying at terminal, changing of lines if actual ship lines are not efficient for expected weather conditions, and if is consider best solution, suspending of loading and moving of ship in a safety area, like protected anchorage or inside port area.

No risk will be accepted knowing the results of any failure of operation.

References: