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# THE SAFETY OF TANKERS AND SINGLE POINT MOORING DURING LOADING OPERATIONS

**Vytautas Paulauskas**

*Klaipėda University, H. Manto g. 84, LT-92294 Klaipėda, Lithuania*
*E-mail: donatasp@takas.lt*

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**Abstract.** Single point mooring (SPM) is used when typical port facilities cannot be applied. Offshore platforms and terminals producing oil and gas are the places where SPM can be employed. Accidents with SPM equipment and ships occurring during loading or unloading operations are very dangerous and may cause serious losses due to the high prices of tankers and facilities and because of polluting the environment with poisonous materials. Any possibilities of decreasing risk and increasing safety are very important. This paper presents the analysis of dangerous situations with tankers and SPM, discusses theoretical basis for study and makes practical calculations and recommendations on decreasing accidence probability during loading operations.

**Keywords:** single point mooring (SPM), tanker, mooring ropes.

## 1. Introduction

In a number of places worldwide, including the Baltic Sea, the North Sea, the Norwegian Sea and other water territories in Europe, North and South America etc. offshore single point mooring (SPM) is used for loading tankers with oil, gas and chemical products as stated by Southworth and Peterson (2000).

The safety of tankers is a very important aspect because large capacity tankers are mainly loaded via SPM (60000 DWT and more) (Paulauskas 2006; Česnauskis 2007). The accidents occurring in tankers, towboats, terminals or SPM frequently relate to personnel's lack of knowledge about the forces and types of energy working under such conditions. The mechanism of forces and moments under the above introduced conditions can be evaluated referring to Ventcel (Вентцель 1969). According to Baublys (2007), Česnauskis (2007), Jaržemskis and Vasilis Vasiliauskas (2007), Afandizadeh and Moayedfar (2008) a deep knowledge and understanding of the processes taking place in terminals and proper actions are very important for increasing the safety of a similar type of offshore facilities and tankers in order to result in a friendly environmental situation in such an important sector of economy.

## 2. Manipulating SPM Aspects and Theoretical Basis

One of the main reasons for using SPM is work with bigger vessels because they can not entry ports (Recommendations of the Committee … 2000). In case the mass of a ship is large, inertial forces and energies are powerful, and therefore increase risk to ships and SPM facilities.

Rare accidents happening in SPM and tankers at the same time are very risky due to the huge mass of ships and large quantities of hazardous goods on tankers and require a more detailed study of all SPM operational aspects (Baublys 2003). A typical working scheme is shown in Fig. 1.

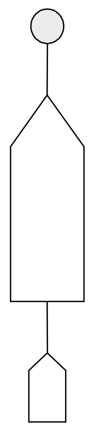

**Fig. 1.** A typical scheme of functioning SPM

Forces created by a tanker moored to SPM, for example waves, can be found on the basis of the orbital theory that can be explained as follows (Paulauskas 1998):

$$X = a \cdot \cos\frac{2 \cdot \pi \cdot t}{\tau}, \tag{1}$$

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$$Y = b \cdot \sin\frac{2\cdot\pi\cdot t}{\tau}, \quad (2)$$

where: *a, b* – coefficients (integration constants); τ – a period of forces acting, for example wave period.

First derivative expresses speed:

$$X' = -\frac{2\cdot\pi}{\tau}\cdot a\cdot\sin\frac{2\cdot\pi\cdot t}{\tau}, \quad (3)$$

$$Y' = \frac{2\cdot\pi}{\tau}\cdot b\cdot\cos\frac{2\cdot\pi\cdot t}{\tau}. \quad (4)$$

Second derivative expresses acceleration:

$$X'' = -\frac{4\cdot\pi^2}{\tau^2}\cdot a\cdot\cos\frac{2\cdot\pi\cdot t}{\tau}, \quad (5)$$

$$Y'' = -\frac{4\cdot\pi^2}{\tau^2}\cdot b\cdot\sin\frac{2\cdot\pi\cdot t}{\tau}. \quad (6)$$

Forces created by a tanker moored to SPM can be calculated as follows:

$$F_x = m\cdot X'', \quad (7)$$

$$F_y = m\cdot Y'', \quad (8)$$

where: *m* – mass of a ship.

Maximum forces that could be created by periodical forces, for example, waves will be in cases:

$$\cos\frac{2\cdot\pi\cdot t}{\tau} = 1, \quad (9)$$

$$\sin\frac{2\cdot\pi\cdot t}{\tau} = 1. \quad (10)$$

Finally, the force acting on SPM will be

$$F_{out} = \sqrt{F_x^2 + F_y^2}. \quad (11)$$

The above mentioned forces should be compensated by a mooring rope. Sometimes, the tanker comes too close to SPM (Fig. 2) and the tug starts pulling the tanker with full speed. As a result, the tanker starts moving.

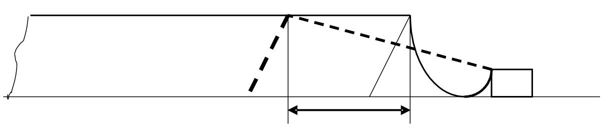

**Fig. 2.** A possible position of the tanker regarding SPM and distance ΔS

Calculations and practical experiments show that in the end (when the tanker goes on mooring a rope line), the tanker can reach speed up to 0,3–0,5 m/s. The increased length of the mooring rope can be up to 5–7% of the total length. The forces created by the tanker on the mooring rope can be calculated as follows:

$$F = m\cdot\frac{dv}{dt}. \quad (12)$$

To calculate acceleration ($\frac{dv}{dt}$), it is necessary to calculate tanker's speed at the end of the process going on the mooring rope. The above discussed speed can be calculated from ship's running speed, mass and forces that create tug (bollard pull) dependence in the following way:

$$v = \sqrt{\frac{2R_0\cdot\Delta S}{m\cdot\ln\frac{F_T}{F_T - R_0}}}, \quad (13)$$

where: $R_0$ – ship's resistance in case of sailing with speed $v$; $F_T$ – tug's bollard pull.

The tanker reaches the length of the mooring rope line and should be stopped at distance $\Delta l$ that depends on the characteristics of the mooring rope and have the possibility of increasing the length up to 5–7% of the total mooring rope length (Southworth and Peterson 2000). In this case, speed change can be found in the following way:

$$dv = \frac{v - v_f}{2}, \quad (14)$$

where: $v$ – maximum towage speed; $vf$ final speed at the end of increasing the length of the mooring rope should be equal to 0, and finally, the last formula can be as follows:

$$dv = \frac{v}{2}, \quad (15)$$

where: $dt$ – time change can be found as:

$$dt = \frac{\Delta l}{dv} = \frac{2\cdot\Delta l}{v}, \quad (16)$$

Finally, acceleration will be:

$$a = \frac{dv}{dt} = \frac{v^2}{4\cdot\Delta l}. \quad (17)$$

As a result, the force of the mooring rope can be calculated as follows:

$$F = \frac{m\cdot v^2}{4\cdot\Delta l}. \quad (18)$$

Additionally, in case the wind, waves and a tug act together, the total possible force can be calculated as follows:

$$\sum F = F + F_{out}\cdot\cos q_{out}, \quad (19)$$

where: $q_{out}$ – the wind, waves and a current acting angle could be found as a result of the acting direction of the inner forces which means:

$$\cos q_{out} = \frac{F_a \cdot \cos q'_a + F_w \cdot \cos q'_w + F_c \cdot \cos q'_c}{F_a + F_w + F_c}, \quad (20)$$

where: $q'_a, q'_w, q'_c$ – a curse angle of the wind, waves and current; $F_a$, $F_w$, $F_c$ – constant wind, waves and current forces.

Finally, the total force of the mooring rope can be calculated as follows:

$$\sum F_T = F + F_{out} \cdot \cos q_{out} + F_a \cdot \cos q'_a + F_w \cdot \cos q'_w + F_c \cdot \cos q'_c. \quad (21)$$

If forces $\sum F_T$ are stronger than the capacity of the mooring rope, the latter one or other element of the system, for example, a mooring rope, SPM construction, anchors, anchor chains etc. can be damaged. The result of the above mentioned acting forces is damage to the weakest element in the system which is usually a mooring rope. SPM anchors sometimes drift or a few elements simultaneously can be damaged.

The presented methodology for calculating forces could be used for specific practical tasks to find real forces and possible damages.

## 3. Practical Calculations and Testing

Practical calculations and testing were made under specific SPM conditions for the methodology presented in this article. Additionally, calculation results were checked applying navigational simulator SimFlex Navigator and conducting investigations into real SPM accidents.

Calculations and testing were made for the VLCC class tanker having the following characteristics:

- length maximum – 345 m;
- length between perpendiculars – 320;
- width – 52 m;
- draft – 21.8 m;
- displacement – 345 000 tons.

The calculations, testing and experimental results of the speed of the tanker depend on towage distance and tug bollard pull force and are presented in Figures 3 and 4.

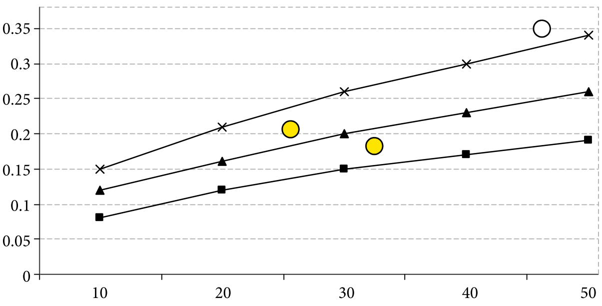


**Fig. 3.** Tanker's speed depending on distance ΔS and the pulling force of tug's bollard

The dependence of the forces on the mooring rope and SPM facilities depend on ship's mass and speed in case the length of the mooring rope is 50 m and a possible increase in the length of the mooring rope makes 2%, 4%, 6%, 8% and 10%, Calculations, testing and experimental results are presented in Fig. 5.

Forces created by tankers in the studied situations are dynamic forces which start acting from the tanker and follow the chain – a tanker – a mooring rope – SPM construction – anchor chains – anchor – to the end of the system. In case there are not enough anchors to keep the force, the anchors start moving (drifting). In case there are enough anchors keeping capacity, forces start acting on anchor chains. In case anchor chains have enough strength, forces start acting on SPM constructions. If SPM constructions are strong enough, forces start acting on the mooring rope.

A mooring rope is the weakest part of the system – a tanker – SPM – created by designers. If forces acting on the mooring rope are too strong, the process of liq-

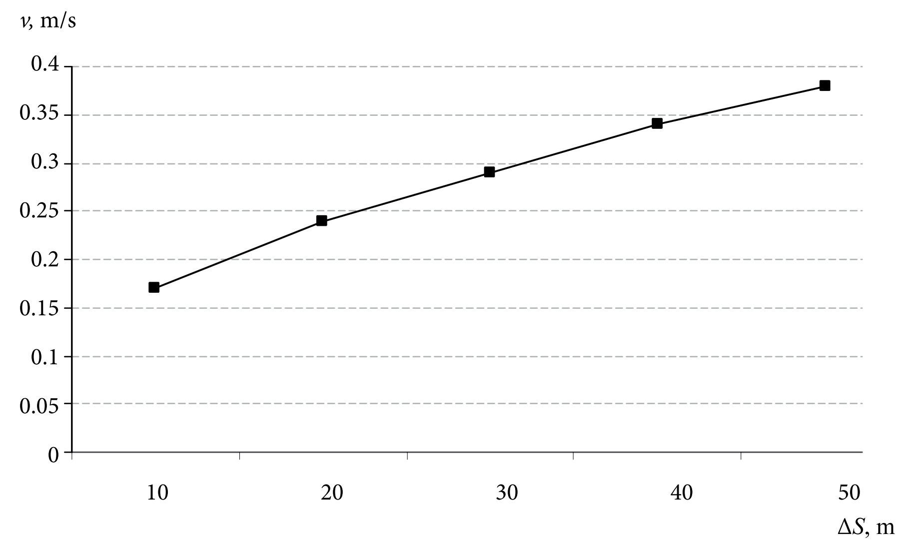


**Fig. 4.** Tanker's speed depending on distance ΔS and 50 T pulling force of tug's bollard

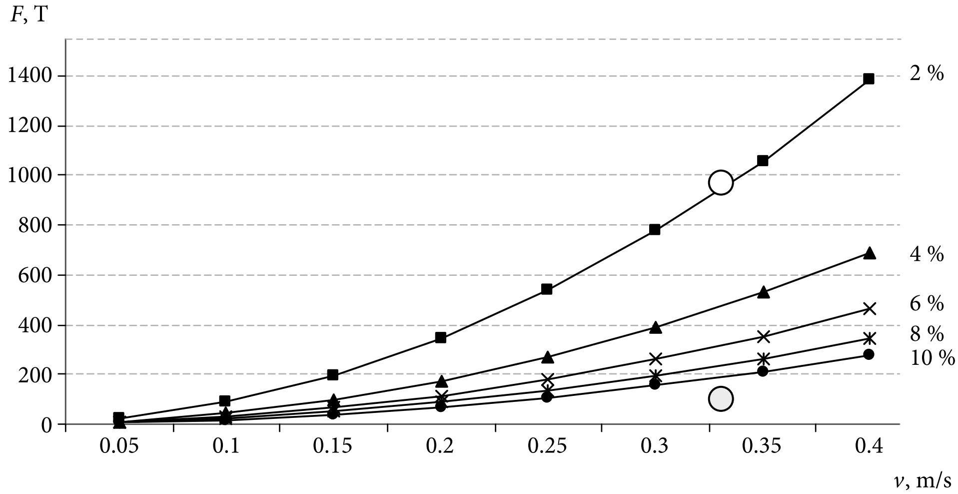


**Fig. 5.** Forces created by the tanker in the mooring line (deadweight 345 000 t) depending on moving speed in case of 50 m length mooring rope and having 2%, 4%, 6%, 8% and 10% increase in the length of the mooring rope

uid pumping must be automatically stopped because the mooring rope can be broken (Paulauskas 2004). The above described process takes only a few seconds and in case of a broken mooring rope and a failure to stop a tanker, movement cargo horses can be broken and liquids (oil products) can pollute the sea environment.

Accidents with SPM in some seas show that personnel working in terminals, tankers and tugs frequently wrongly interpret the mechanism of dynamic forces. The investigated accidents in SPM show that researchers mainly focused on damaged elements and did not take into account the reasons for difficulties claiming the elements of SPM system as wrong or weak. Accidents taking place in terminals, for example in Butinge in 2003, were investigated by a special committee formed by the Government. The conclusion of the latter accident discloses that a mooring rope was too weak, though in fact, the quality of the rope was good enough. In reality, when a tanker approaches close to SPM, in the majority of cases, the tug starts pulling at full speed and the tanker reaches relatively high speed before the mooring rope is strained under a load. Therefore, due to the actions performed by the tug and a huge mass of the tanker, strong dynamic forces are created and can result in the drifting of anchors, deformations of anchor chains, breaking a mooring rope and cargo horse etc. In such cases, some oil outflow from the broken cargo horse might appear and pollute the sea environment.

A correct understanding of dynamic processes and forces acting in the mechanism tug – tanker – SPM can support in optimizing the design, maintenance and exploitation of SPM systems and help with avoiding accidents.

## 4. Conclusions

1. SPM systems are used in many regions as they require less investment in comparison with traditional port systems and facilities.
2. Methodology for calculating possible forces in SPM system presented in the article has a good correlation with tested results received under real SPM conditions and can be used for practical calculations.
3. A correct understanding of dynamic processes and forces acting in a ship moored to SPM or a tug can assist in optimizing design, maintenance and exploitation processes as well as in avoiding accidents.
4. Training of personnel working in the terminal and ship for a better understanding of dynamic processes in the system SPM – tanker – tug should help with avoiding errors in exploiting terminals and increasing the safety of tankers and SPM.

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