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The Mooring Pattern Study for Q-Flex Type LNG Carriers Scheduled for Berthing at Ege Gaz Aliaga LNG Terminal

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ABSTRACT: Ever growing energy industry requires larger quantities of LNG to be transported by bigger ships between terminals. Every day, new kind of large vessels created by new technologies, and these are used to trade around the globe. This is the dynamic change in shipping industry. But on the other hand these new vessels need to safely berth to existing terminals which we may accept as more static part of the trade.
Thus this study born by the request of Ege Gaz Aliaga LNG Terminal management to determine if it is safe to berth to the terminal by a new breed of large LNG carrier type named as Q-Flex and Q-Max. Transas Bridge Simulator NTPRO 5000 series was used in this study for extensive experiments which had been simulated by the use of hook function. During the study, every force applied to mooring hooks and dolphins by the ship lines were divided into 3 dimensions and then measured by simulation experiments. With analysis of the data, required hook and dolphins strengths were determined for the safe mooring arrangements. Upon the completion of the study Ege Gaz Aliaga LNG Terminal became the first safe berth for Q-Flex type vessels in the Mediterranean and the Black Sea. And finally all experiments were confirmed with real life experience when the first Q-Flex type LNG carrier berthed to the Ege Gaz Aliaga LNG Terminal.

1 INTRODUCTION AND MOTIVATION

Due to ever energy hunger economies of the world the natural gas trade market has seen a rapid growth in the last 20 years. (David A. Wood 2012) Also due to geographical and political reasons natural gas industry has been forced to provide other ways than the pipe lines to deliver the commodity to required markets.

Thus Liquefied Natural Gas Carrier ships have born. First LNG carrier "Methane Pioneer" has left Calcaseieu River on 25 January 1959 and she was a tiny one compared to today's standards only having 5034 tons deadweight. Growing market and advantage of cost in bulk carriage also boost the size and change the characteristic of LNG carriers (Starosta, 2007). Today's the biggest LNG carrier is a giant of a ship "Q" type LNG carriers with 345 meters length over all and has a cargo capacity of a 266.000 cubic meters which equals to 161.994.000 cubic meters of natural gas. This is the dynamic change in shipping.

But on the other hand as this LNG trade is done via seaway since 1959 there are lots of already constructed coastal facilities which are used to accept this highly specialized cargo but from smaller ships. Due to the great initial building costs of such facilities, it is extremely hard to construct new terminals from scratch for every new breed of LNG carrier borns. Thus it is been accepted that this part of the trade is much more static.

Nevertheless with careful planning, study and with the calculation of risks an existing terminal might be evaluated that if it has correct arrangements and qualities to receive the new class of ships or the new requirements for the terminal to safely accept the ships which might not even been discovered when the terminal was first planned.

Mostly above risk analyses for LNG terminals and shipping depend on computer models (Er, 2007).

2 MOTIVATION OF THE STUDY

This study is born by the request of Ege Gaz Aliaga LNG Terminal Management to determine if it is safe to berth to their existing terminal by a new breed of large LNG carrier type vessel named as Q-Flex.

Aliaga LNG Terminal which one of the two existing LNG Terminals in Turkey is constructed between 1998 and 2002 and has started its operation in 2006. Strategic technical specifications of Ege Gaz Aliağa LNG Terminal are stated below;

- Ege Gaz Aliağa LNG Terminal has 2 full containment LNG storage tanks, each with a capacity of 140000m^3,
- Ege Gaz Aliağa LNG Terminal's meteorologically convenient position and direction allow for the efficient passing of ship traffic,
- Re-gasification and send-out capacity: 6 bcm/y of high pressure,
- Jetty design : Capable of handling the largest LNG carriers in the world and has a 17 meter draft

Location of Ege Gaz Aliağa LNG Terminal is shown in Figure 1.

Figure 1. Location of The Ege Gaz Aliağa LNG Terminal

But as described below first Q-Flex vessel was not even built in 2006. In detail, "Q" type LNG carriers are the state of the art vessels which are designed to be more efficient and clean than the regular LNG carriers and first delivered to service in 2007. They were designed as membrane type carriers and have a capacity between 210.000 and 216.000 cubic meters which makes them the world's largest carriers until the entry into service of the Q-Max type LNG carriers. Principal dimensions and the tonnages of the "Q" type LNG ships are shown in Table 1.

In the completion of this study it is revealed that if the terminal is compatible with the Q-Flex type vessels without any new upgrade in terms of equipment or construction or not.

Table 1. Principal Dimensions and Tonnages of the "Q" Type LNG Ships

"Q" Type LNG Ships	Q-Flex*[1]	Q-Max*[2]
LOA	315 m.	345 m.
LBP	302 m.	332 m.
Breadth	50 m.	53,8 m.
Draught (Loaded)	12,50 m.	12,2 m.
Draught (Ballast)	9,60 m.	9,60 m.
Sea Speed (Loaded)	21,1 Knots	20,1 Knots
Capacity	217.000 m^3	265.940 m^3
DWT	109.502 ton	130.128 ton
GRT	135.848	163.922

*[1] M/V Al Shamal (Samsung HICL)
*[2] M/V Al Dafna (Samsung HICL)

3 METHODOLOGY

3.1 *The aim of the study*

The main aim of this study is to find a reliable and verifiable and risk free solution to determine the required mooring pattern arrangements of a specific terminal for safe maneuvers of a specific ship type before such an event happens in reality.

The term "mooring pattern" refers to the geometric arrangement of mooring lines between the ship and the berth (OCIMF, 2008). Manifolds connection and other interfaces are not in the scope of the study.

It should be noted that the industry has previously standardized on the concept of a generic mooring layout, taking into account Standard environmental criteria. The generic mooring layout is mainly applicable to a "multi-directional" environment and to the design of ship's mooring equipment. For general applications, the mooring pattern must be able to cope with environmental forces from any direction. This can best be approached by splitting these forces into a longitudinal, lateral and a vertical component and then calculating how to most effectively resist them.

The ship's mooring lines should be able to hold the ship in position with wind speeds of 60 knots (31m/sec) (OCIMF. 2008; 18). Q Flex type vessel have 20 sets of mooring lines with ø44 mm. ultra high molecular weight polyethylene. Each mooring line has MBL of 137 tons. However, the SWL value of terminal mooring arrangements should be not less than MBL of the ship mooring line (OCIMF. 2008; 26).

3.2 *Preparation for Simulation Experiment*

Studies were prepared according to OCIMF (2008) Mooring Arrangements Guide 3rd Edition, SIGTTO "Prediction of Wind Loads on Large Liquefied Gas Carriers" and various other sources.

Study was begun with the preparation of model simulation of Ege Gaz Aliaga LNG Terminal and development of area simulation. Q-Flex Type LNG carrier's loaded and ballasted models were supplied from Transas Company.

Supplied model LNG 10, had been installed to bridge simulator. During the verification test on the LNG 10 model, mooring arrangement was found inconsistent with real Q-Flex Type LNG carrier.

In this context, simulation model's mooring arrangement was requested to be re-developed by Transas Company according to real Q-Flex LNG carrier's mooring arrangements blueprint. Re-developed and corrected LNG 10 model had been tested for re-validation.

In the process, simulation model's different characteristics were compared with the real ship and aerodynamic coefficients of LNG 10 Model have been found inappropriate. Simulation model's aerodynamic coefficients were requested to be re-developed by Transas Company.

Lastly re-developed and corrected model and area simulation were installed to bridge simulator to be used in project experiments. Also experience of RasGas Company and Aliaga LNG Terminal Management's experts are consulted to confirm reliability and validity of simulation models.

Then the Transas Bridge Simulator NTPRO 5000 series was used for extensive experiments which had been simulated by the use of "Hook" function. Every force applied to mooring hooks and dolphins are calculated and recorded.

3.3 *Reliability of Data collection method*

To analysis the data obtained from simulation experiment hook function, the mathematical model of the simulation is have to be examined according to the "mathematical models technical description" of Transas;

The ship itself is a controlled object. The steering gears are propellers, rudders, anchor and mooring systems etc. These mean the forces on ship hull. The value of forces directly depends on the control value changes.

Though actual ship motion in real world can only be described with consideration of additional external forces. External forces deriving from wind, current, waves, channel geometry (the influence of water depth, walls, bottom inclination, etc.) and the presence of other objects (moving or immovable) are shown in Figure 2.

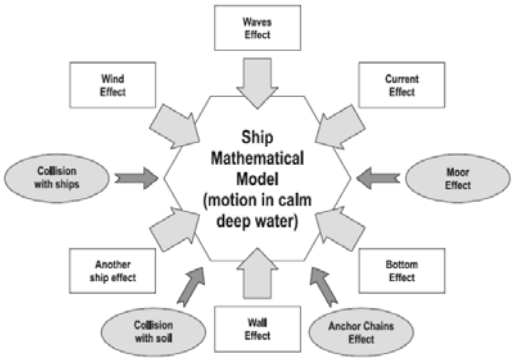

Figure 2. External Forces on the Ship Model

Thus, it is extremely important to consider the environmental conditions used for mooring model in the study.

Simulation's mathematical wind model can be expressed as follows: The air flow around the ship is considered as uniform flow of constant direction and velocity. The wind velocity at given Beaufort number is obtained as average value of wind velocity at 6 meters height above the sea level. Formulas for calculating the aerodynamic forces and moments are as follows; aerodynamic longitudinal force (F_{xA}), aerodynamic lateral force (F_{yA}), aerodynamic vertical force (F_{zA}), vessel course (φ), relative wind direction (φ_w), and speed (V_w) as shown in Figure 3.

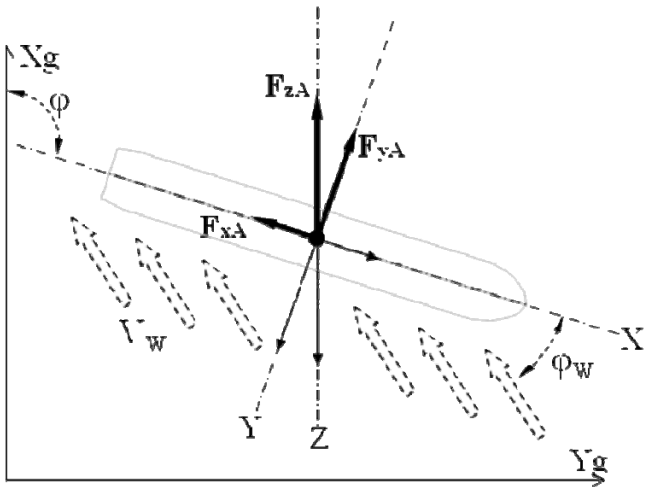

Figure 3. Wind Forces

For the environmental conditions used in simulation experiments, OCIMF's Mooring Equipment Guidelines Third Edition (2008) is taken as reference for Mooring Model Study in compliance with the local meteorological data gathered and verified from various sources.

Wind : 30m/sec
Current : 0,1m/sec – 004^0
Wave : 0 meters

As can be seen from above values the most dominant and important environmental condition is determined as wind. Even though the prevailing wind in the region is from NNE – NE, according to multi-directional environmental forces mentioned in Mooring Equipment Guidelines, wind was taken from every angle in 10 degree steps for 180 degree.

Relative and true directions of the winds used in simulation experiments are shown in Figure 4. In relation to the wind velocity, 30m/sec is the highest possible wind velocity which can be applied in Bridge Simulator, Thus 60 knots of wind velocity couldn't be reached in simulation experiments and the highest value, 58,3 knots (30m/sec) was applied.

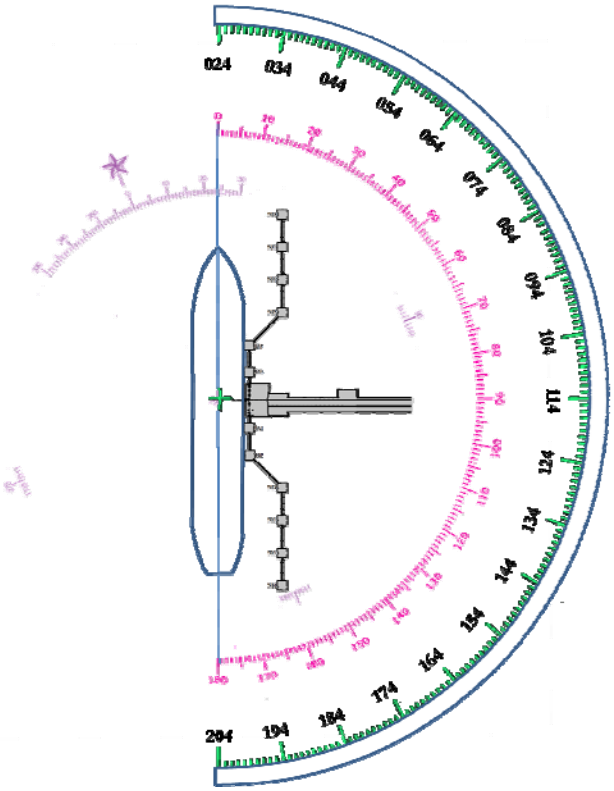

Figure 4. Wind Directions Used in Simulation Experiments

In simulation experiments, formulas for calculating the aerodynamic force components are as follows (Transas, 2003);

$$F_A = \left[C_{AH}(\varphi_{wk}) + dC_A(\varphi_{wk}, A_N)\right] 0.5 \rho_A V_A^2 (A + A_N)$$

F_A = Aerodynamic force components
C_{AH} = Non-dimensional aerodynamic force components
φ_{wk} = Relative wind velocity
dC_A = The additional values of non-dimensional aerodynamic force components due to the superstructures.
A_N = The superstructure area projected to the central plane and to the midship plane
ρ_A = Relative wind angle velocity.
V_A = Relative wind velocity.
A = The above water hull area projected to the central plane and to the midship plane.
A_N = The superstructure area projected to the central plane and to the midship plane.

Structural formulas for complete aerodynamic characteristics calculating are defined by functions represented by partial sums of Fourier series.

Coefficients are depended on the superstructure area and above-water hull area and are provided in the database of the software.

Another important factor for mooring pattern study is of course the mooring arrangement of ship and the terminal.

For the reliability and validity of the study, a real Q-Flex Type vessel, M/T Al Huwaila's data was taken as a reference in simulation experiments and data is listed below. They are used with same values in experiments.

Number of Mooring Ropes: 10 at bow 10 at aft total 20 pieces mooring ropes.
Type of Mooring Ropes: Ultra High Molecular Weight Polyethylene
MBL of Mooring Ropes: 137 tons (Max. BL)

Terminals mooring arrangements are also shown in the Figure 5 in relation to the Q-Flex type LNG carrier. Each mooring line fastened to a hook on the dolphins. Angles and distances of the mooring lines were automatically calculated by simulation software which accepted the mooring pattern of the vessel as generic mooring layout.

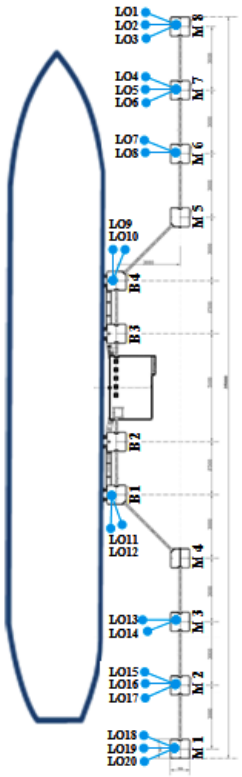

Figure 5. Mooring Model

Transas software's mooring model can be described as follows: The mooring gear consists of the mooring lines and docking winches. Mooring line diameter and type, winch type, choke positions are taken into account.

A mooring line is modeled as a weightless stretchable thread without considering its special configuration. The model describes the influence of mooring lines from the winch to the another ship's choke, bollard or mooring ring. Two winch operation conditions are examined: constant length conditions ("stop" conditions) and constant tension condition. The last condition supposed to have constant value of the force at ship's end of tow-line. The force is considered to be directed along the tow-line. Both conditions are used in this study.

3.4 *Mooring pattern simulation Experiments and Analysis*

It was determined that the ballasted ship with bigger wind effect area is always giving higher value results. Thus it was considered that the ballasted ship model was better suited to measure the required strength of mooring arrangements of the terminal.

Totally 20 ropes had been moored to hooks on dolphins for LNG model 10 and then 16 tons of force was applied to each one automatically. For start of LNG 10 model simulation experiment, equilibrium of forces on the hooks and equalization of rope lengths were waited.

Whenever an environmental condition was changed, to acquire the correct data, equilibrium of forces on the hooks should be waited. To reduce the waiting times "Fast Time Simulation" practice was used.

First installed environmental condition was current in the experiment. Current's effects on the hooks had been observed but found negligible for recording. Thereupon wind was installed to experiment from 000^0 relative direction with the velocity of 10m/sec.

When forces had been equalized wind velocity was increased to 20m/sec. After the new equilibrium had been achieved, wind velocity was increased to upper limit of Bridge Simulator, to 30m/sec. Equilibrium of forces on hooks was waited when 30m/sec velocity was reached.

Data recorded after forces were equalized. Equilibrium process of forces on the hooks is shown in Figure 6.

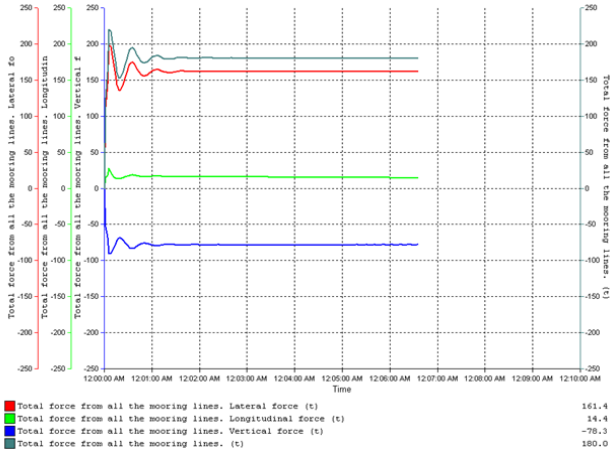

Figure 6. Equilibrium process of forces on the hooks

Afterward wind direction had been started to change by 10^0 steps in clock wise rotation. Each time oscillations had been waited to reach equilibrium and then data of longitudinal, lateral and vertical forces on the each hook was recorded.

During simulation experiments the force applied to hooks separately identified as 3 different components longitudinal, lateral and vertical. Diagram of these force components are shown in Figure 7. As can be seen in Figure 6 longitudinal forces' direction towards to the bow of ship was taken as (-) and direction towards to the stern of the ship was accepted as (+). Lateral forces' direction to the terminal was taken as (-) and direction away from terminal was accepted as (+). Vertical forces' upwards direction was taken as (-) and downwards direction was accepted as (+).

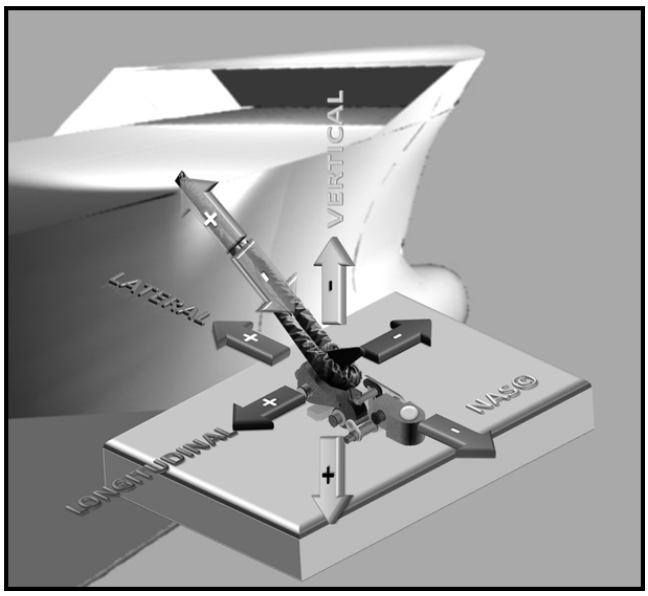

Figure 7. Components and Directions of Forces on the Hooks

In simulation experiments, each force component occurred on each hook from every wind direction was measured and recorded separately. Furthermore, obtained data is shown in graphics. An example graphic of the #1 hook is given in Figure 8.

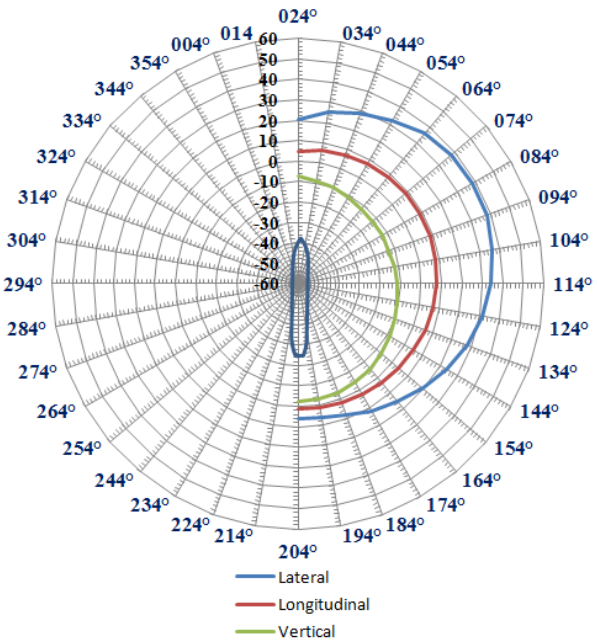

Figure 8. Force Components on the # 1 Hook

3.5 *Mooring Model Simulation Experiment Results*

Detailed data of each longitudinal, lateral and vertical force component on every mooring hook is measured. Based on this data, detailed total longitudinal, lateral and vertical forces occurring on each dolphin were calculated.

From this data because of environmental conditions, the maximum occurred longitudinal, lateral and vertical forces, on dolphins were calculated and shown in Table 2. As the lateral forces, the maximum force of 139,3 tons occurred on M7 dolphin. As the longitudinal forces, the maximum force of 109,1 tons occurred on B1 dolphin. As vertical forces, the maximum force of -52,5 tons occurred on M7 dolphin.

Table 2. Total Forces Occurred on Dolphins

Dolphin Number	FORCES Lateral	Longi.	Vertical	Total SWL
M1	125,8	-33,4	-33,4	3x150=450
M2	117,3	17,9	-34,4	3x150=450
M3	49,0	33,4	-16,8	3x150=450
B1	14,6	109,1	-34,3	2x150=300
B4	15,4	-100,1	-33,2	2x150=300
M6	85,1	-30,6	-36,7	3x150=450
M7	139,3	14,5	-52,5	3x150=450
M8	115,3	23,7	-38,4	3x150=450

The maximum calculated force values that caused by Q-Flex Ballasted LNG Carrier which is berthed at Ege Gaz Aliaga LNG Terminal and under environmental conditions of 30m/sec wind from various directions and with a stable current of 0.1m/sec are compared with the SWL value of terminal mooring arrangements.

4 CONCLUSIONS

According to the comparison between the existing hooks' SWLs and the forces which will be occurred on the hooks when Q-Flex vessel berthed, it is determined that mooring equipment are well sufficient for such forces.

This study revealed that Ege Gaz Aliaga LNG Terminal is well suited and a safe berth for Q-Flex Type LNG carriers. Upon the completion of the study Ege Gaz Aliaga LNG Terminal became the first safe berth for Q-Flex type vessels in the Mediterranean and the Black Sea. And finally all experiments were confirmed with real life experience when the first Q-Flex type LNG carrier berthed to the Ege Gaz Aliaga LNG Terminal (25.11.2011).

Also this study revealed that adequate bridge simulation systems can be used to evaluate the compatibility of the more static part of shipping bussiness like terminals to more dynamic part of shipping as ships reliabily, efficiently and without taking any unnecessary risks in terms of mooring pattern and arrangement studies.

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