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TECHNICAL NOTE

Evaluating the Validity of Quasi-Static Analysis for Prediction of Vessel Mooring Line Forces

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ABSTRACT

Quasi-Static analysis of moored vessels is vastly used for engineering designs, as a substitute to the numerical simulation of dynamic mooring analysis. Yet, the level of validity of the results of quasi-static analysis is a matter of discussion. In the present study, the validation of the assumptions behind the quasi-static analysis of mooring vessels is examined with application of a dynamic model for a number of vessel sizes and mooring configurations. The results show that in the moderate wave condition (wave height less than 1.2m), the main assumption of not applicability of wave forces in prediction of line forces is acceptable; the differences being less than 5 percent. However, distribution of forces between spring and breasting lines is not coincided with the anticipation of response of the system. The parametric study shows that the critical condition for line tensions is not necessarily corresponding to the exact coincidence of directions of wind, current and wave forces. Also, the forces exerted on fenders in some cases are maxima in direction, different from the perpendicular to the vessel. This means that the mooring line arrangement considerably dictates the distribution of the tension in mooring lines and reaction in fenders. Hence, the accuracy of the quasi-static analysis highly depends on the mooring lines configuration.

1. Introduction

The purpose of quayside mooring at piers, jetties and islands is to safely hold a vessel in a certain position to facilitate loading/unloading, storage, maintenance etc. and to insure smooth port operation while the vessel is moored. Mooring configuration and components should be designed and constructed to resist the nominal loads in all expected load combinations for every type of mooring service, without exceeding the appropriate allowable stresses for the mooring components. Due to the dynamic nature of both the excitation and response, accurate calculation of tension in cables or loads exerted to mooring points requires that the system dynamics are accounted for. However, practical experience has shown that in many situations, static analysis tools can be used to determine reliable mooring designs in harbors, where the wave height is limited and therefore the wave action on vessel in not dominant. For such conditions, wind and current are the main excitation drivers. Although winds can be highly dynamic, practical experience has shown that for typical vessels a wind with duration of 30 seconds can be used as a constant (non-dynamic load). Therefore there are some formulations in which the dynamic nature of the exciting forces and the response of the system are simply disregarded. These formulations consider the static equilibrium in the mooring line only. This approach is called static or “quasi-static” design [1].

Nevertheless, due to the uncertainty which exists in the results of this method, extra safety factors are inevitably applied [2]. Effects due to the dynamic behavior and the interaction between vessel motion and mooring lines, which can be considerable, are not considered in simplified static method [3].

Therefore, validation of traditional quasi-static models through dynamic models have recently been subject to several studies to determine good engineering practice [4].

Dynamic analysis is based on theory of mass-spring systems and involves solving systems of linear (or nonlinear) equations of motion. There are two general approaches to "dynamic" mooring analysis: (1)

frequency domain analysis and (2) time domain analysis. The first approach is numerically more convenient and requires less computational efforts. However, the second one is more accurate and can account for slowly varying wave drift forces more properly [5].

Dynamic mooring analysis inevitably involves the numerical simulation of vessel motion. The method is rather complicated, time consuming. On the other hand, the quasi-static method is quite handy and practical in engineering applications. Nevertheless, the level of validity of the results is debatable.

In the present study, the validation of the assumption behind the quasi-static analysis is examined with application of an advanced dynamic model for a number of vessel sizes and mooring configurations. For this purpose, a dynamic analysis of the mooring system of a LPG jetty in Kharg Island in Persian Gulf is described for three different vessel sizes. The jetty is an open berth, i.e. no protected harbor is considered. The design vessels include three sizes of 10000DWT Pentane, 30000DWT Condensate and 50000DWT (80,000 cubic meter) LPG vessels [6]. Parametric studies are conducted to study distribution of mooring line tensions and reaction forces on breasting points in the dynamic model, and to determine eventual deviations from the behavior expected from the quasi-static analysis.

2. Environmental conditions

2.1. Environmental forces

Wind data: one year return period wind speeds in various directions are considered in this study. The variation is between 8.9 m/s in South-Western direction and 16.9 m/s in Northern direction [7].

Wave Data: At the berthing location, design waves heights and periods for return periods of 1 and 100 years for various directions have been determined in [7]. As with wind, waves with one year return period are considered for downtime analyses. Waves are modeled as irregular sea states generated based on a standard Jonswap wave spectrum. The significant wave height varies from 0.32 m in South-Eastern direction to 2.67 m in West-North-Western direction.

Currents: According to [6], maximum operational current velocities of 0.66 m/s occur for both flood and ebb in the directions 135° and 315°.

Tide: Since tidal changes are accommodated by tightening or loosening mooring lines, the effect of tidal forces was not considered on vessels and mooring lines.

Water depth and water levels: In the model, the water depth of 17 m is simulated. This is the depth during the lowest water level (+0.0 m CD) at the platform location. Since the lower depth produce higher current force, this condition is considered critical. It should be noted that the water is shallow and the hydrodynamics are therefore expected to be rather nonlinear.

2.2. Load cases

According to shoreline direction, waves can come from 135 ° N to 315 ° N. For each analyzed wave direction, possible wind directions within a 180 ° span with increments of 22.5 ° is considered (wave direction ±90°). This is because in the Persian Gulf, almost all waves originate from wind Sea with few observations of swell sea. Therefore, an abrupt difference in direction between wind and waves is not plausible. Since waves can, in some cases, provide situation in favor of the system, load cases with wind and current but without waves are also considered. In total 31 load cases are considered for the analysis. Fully loaded and ballasted loading conditions are considered for all environmental load cases [8].

3. Mooring Equipment

The port is designed to service three types of 10000DWT Pentane, 30000DWT Condensate and 50000DWT (80,000 cubic meter) LPG vessels [6]. The 50000 DWT LPG-carrier, will be moored using 14 mooring lines: 6 head lines; 6 breast lines and 2 spring lines. The 30000 DWT Condensate Vessel will be moored using 10 mooring lines: 4 head lines; 4 breast lines and 2 spring lines. The 10000 DWT Pentane Vessel will be moored using 8 mooring lines: 4 head lines; 2 breast lines and 2 spring lines. The mooring line arrangement is determined according to the British Standard 6349: Part 4 [9]. Layout of mooing lines of 50000 DWT LPG-carrier vessel is illustrated in Figure 1 as an example. As demonstrated in the figure, there are 6 mooring dolphins (MD in the Figure) and four breasting dolphins (BD in the Figure).

The mooring line characteristics are determined based on reference [9] and [10] (more details in [6]). In modeling of the system, it is supposed that fender and breasting dolphin work such as series of springs with equivalent coefficient. Based on data from calculation of breasting dolphins [11], considering allowable impact force (p) and maximum deflection of pile and fender (δ), the equivalent rigidity coefficient (KT) of each spring is considered 146.3 t/m. Sensitivity analysis has shown that varying KT does not significantly change the mooring forces.

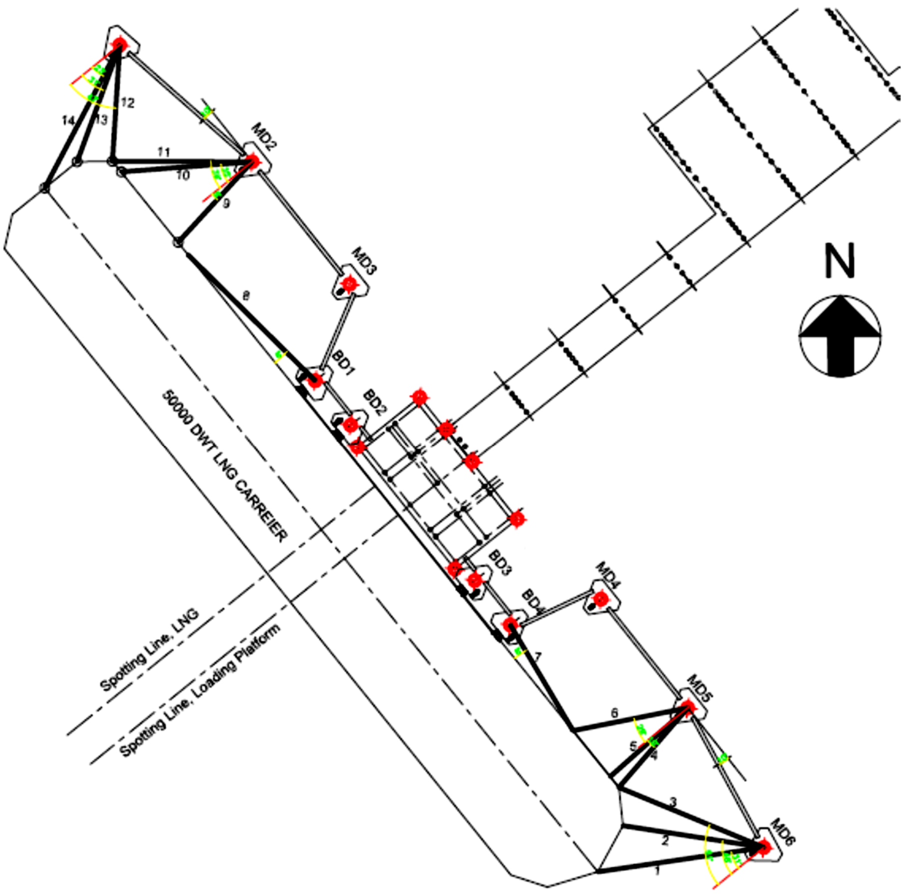

Figure 1. Array and orientation of mooring lines in 50000 DWT vessel

4. Mooring Simulation

Hydrodynamic mooring analysis in this project is performed by MOSES software that is for analysis of structure which will state in the sea in different situations against environmental forces such as wave, wind and current forces. This software is designed by Ultramarine, Inc. [12]. The model numerically solves the system of linear differential equations of motion in frequency and time domain [13].

The basic outputs which are considered in this study are time-series of mooring line forces. The other outputs include vessel displacement and applied force on the fenders, which are important from engineering point of view, for which the criteria from PIANC in terms of maximum allowable displacement are applied for safe operations of oil and gas tankers [14].

5. Parametric study of mooring line forces

Numerous parametric analyses are performed to investigate the behavior of the mooring system against the applied environmental loads. Here, some of the interesting outcomes of the study are presented, mostly those that challenge the assumption and results of static analysis.

5.1. Wave effect

One of the basic assumptions of static analysis in some design manuals is that the effect of wave forces with compare to wind and current forces is negligible [1]. This assumption is practically applied for mild weather, where the jetty is in a protected harbor area. Figure 2 shows the results of dynamic model in terms of mooring line forces for two conditions, one is with (solid lines) and the other without (dashed lines) considering wave forces, for one of the design load cases. The loaded and ballast vessels are presented. The wave height in this case is 1.2m. As can be seen in the figure, the differences are less than 5 percent in magnitude for almost all vessels and loading conditions. Similar results are found for other vessels.

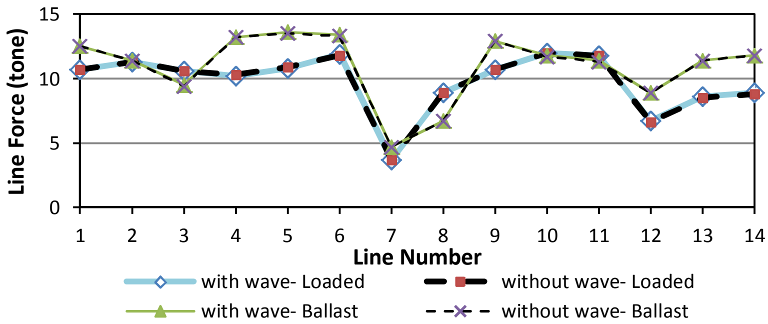

Figure 2. Line forces with (solid) and without (dashed) considering wave forces for loaded and ballast conditions(50,000 DWT)

5.2. Force distribution

One of the main assumptions in the static analysis of mooring forces is that the forces can be separated in two transversal and longitudinal forces and one moment, depending to the shape of the hull and direction of the active forces [1]. With this assumption, one can expect that with forces in transversal direction, the forces in breasting lines become negligible and due to forces in longitudinal direction, the forces in spring lines become negligible. However, the dynamic analysis shows that, although this is valid for the longitudinal direction forces, for forces in transversal direction the resultant forces in spring lines are considerable. Tables 1 demonstrates for a prevailing environmental condition, the ratio of breasting line (BL) per spring line (SL) and ratio of spring line per breasting line for sole longitudinal forces and sole transversal forces, respectively. The transversal forces direction is considered so that the vessel is detached from the berthing points and hence put the lines in tension.

The expectation is that the ratio being very close to zero. However, as can be seen in the table, it is the case only for longitudinal but not for transversal forces. The arrangement of the lines can be blamed for this unexpected result of force distribution against transversal forces. Therefore, although head and stern lines provide a contribution in taking the mooring forces, they will alter the ordinary assumed combination of forces.

Table 1. Ratio of breasting and spring line forces due to sole longitudinal and transversal forces

Vessel (DWT)	Sole Longitudinal forces BL/SL		Sole Transversal forces SL/BL	
	Loaded	Ballast	Loaded	Ballast
10,000	0.19	0.19	1.43	1.14
30,000	0.09	0.11	1.13	0.64
50,000	.02	.03	1.48	0.91

5.3. Sensitivity to wind direction

Figure 3 shows variation of tension force in mooring line 7 (see Figure 1) against wind direction for loaded (solid) and ballast (dashed line). The graphs show results for wave directions West (left) and North-West (right). A direction equal to zero corresponds to along the axis of the ship from stern to bow. All other parameters including direction and magnitude of wave and current as well as wind speed are kept constant. Since line 7 is a spring line, the maximum force is expected to occur for zero wind direction. However, in neither of the plots the maximum force occurs for this wind direction. The trend of variation with wind direction is similar for all vessels, although magnitudes differ.

The results show that a simple judgment of the mooring line forces is difficult to make due to the complex interaction between the different mooring lines, restraints (fenders) and vessel motions.

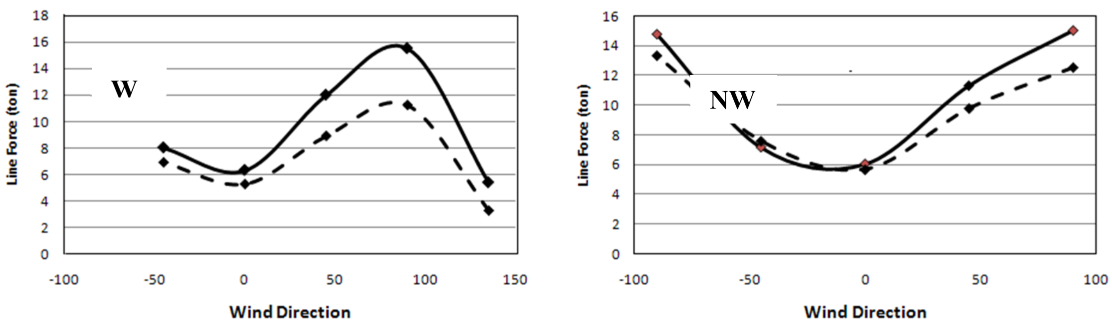

Figure 3. Variation of tension in mooring line against the wind direction for two wave directions. Solid lines are for fully loaded condition and dashed lines are for ballast condition

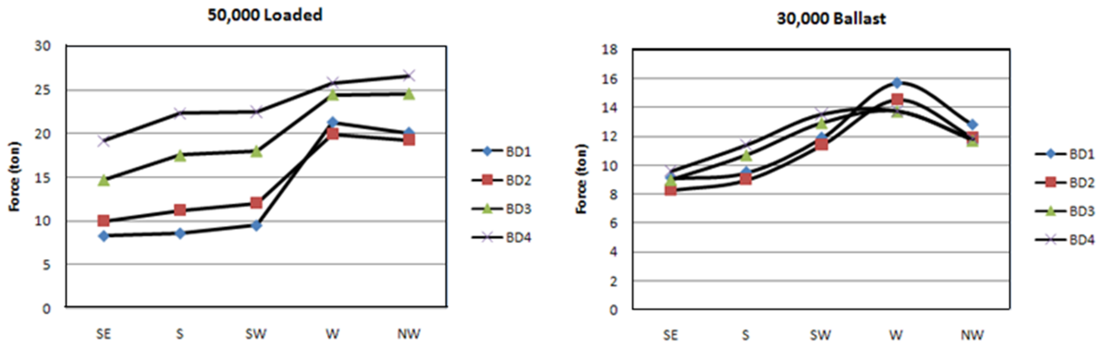

Figure 4. Variation of Forces on fenders due to variation of wave direction

5.4. Fender forces

One other parametric analysis which is discussed here is the effect of wave force direction on the forces exerted by the vessels to the breasting dolphins (fenders). Based on the vessels mooring configuration (Figure 1) we expected maximum load on fenders for collinear wind and current when the wave is perpendicular to the vessel (South-Western direction). This is however not always the case. Figure 4 presents two examples of the forces on the four fenders (designated by BD) for varying wave direction.

In these examples current and wind are kept constant. The wind is in Western direction with a speed of 17.8 knots. As can be observed, SW is not the governing wave direction for the fender forces. On the other hand, in most cases Western direction is governing. Similar results are observed for other wind directions and for various vessels; West being the governing wave direction. These results show the direct effect that mooring line arrangements have on force distribution. This must always be taken into consideration.

6. Conclusion

Quasi-Static analysis of mooring vessels has traditionally been vastly deployed, when the numerical solution of dynamic equation of motion was impossible. Nowadays, with the aid of high speed computers this difficulty is resolved. However, accurate modeling and processing of input and output data is still complicated and time consuming. Appreciating the level of validity of static analysis helps the engineers to escape application of dynamic models at least for early stages of design.

In the present study, the basic assumptions behind the quasi-static analysis of moored vessel to a fixed pier or quay wall are evaluated through the application of an advanced numerical model for three size vessels for a LPG export jetty in Kharg Island, North of Persian Gulf. The software is developed based on the dynamic linear equations of motion of vessel.

The results show that in the moderate wave condition, neglecting time-varying wave forces in prediction of line forces can be a good approximation; the differences are mostly less than 5 percent. On the other hand, distribution of forces between spring and breasting lines depends strongly on the mooring arrangement and is not always straightforward to predict. In the present case studies, for sole longitudinal forces, the forces in breasting lines are nondramatic, however, for sole transversal forces, the forces in spring lines are significant.

As much as the directions of wave, wind and current become close together, as expected, the total forces will be increased. However, the parametric study shows that the critical condition is not necessarily corresponding to the exact coincidence of directions of the above forces; for instant, the change in the direction of the wind, when the other parameters are constant, revealed that the spring line tensions are not necessarily maximum when the forces are all in longitudinal direction. Also, the forces exerted on fenders are maxima in direction rather than SW (perpendicular to the vessels) for incident waves. Again, it means that the mooring line arrangement considerably dictates the distribution of tension in mooring lines and reaction in fenders and therefore, the simple judgment on the performance of the lines against applied loads could simply lead to incorrect conclusion.

From the qualitative evaluation of some mooring cases of the present study, it can be concluded that the level of the accuracy of the static analysis depends not only on the accuracy of the amount of active forces, but also and more significantly on the arrangement of the mooring lines. Therefore, giving exact amount of discrepancy (for instant 10 percent) between quasi-static analysis and dynamic analysis, which is common in engineering practices must be taken with precaution.

7. Acknowledgement

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