CHAPTER 202

Ship Motion Study for the 2010 and 2020 Plan in the San Pedro Bay, California

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Introduction

The Port of Long Beach, in cooperation with the Port of Los Angeles and the Corps of Engineers, has been working on the development of a Master Plan for the San Pedro Bay area. This Master Plan, nicknamed the "2020 Plan", is intended to project the Port's land and channel requirements through the year 2020. Any landfill expansion program would be implemented in phases throughout the life of the Master Plan. The initial phases of such a plan would greatly limit the ability of the Port to revise the future configuration of landfill phases, making it important for the Port to determine a final landfill configuration before implementing the early phases.

In developing the 2020 Plan, the Port projected a need for approximately 2,600 acres of additional land. In attempting to turn this 2,600 acre figure into a landfill scheme, the controlling agencies had to take a number of factors into consideration, including (1) water quality and tidal circulation; (2) potential ship motion problems; (3) additional berths required for future development; (4) land and waterside transportation corridors required; (5) availability of dredge material for creating the land; (6) available areas for creating landfills; (7) efficiency of land usage in various configurations; (8) types of ships anticipated to use the new landfills; (9) types of terminals anticipated to be located on the new landfills.

The Port of Long Beach developed two basic schemes which addressed the requirements listed above. In either case, the landfill configuration for the Port of Los Angeles remained the same. The first scheme (called the island scheme, Figure 1) had the advantage of more closely matching the proposed Port of Los Angeles development. Water quality and tidal circulation would be improved with this scheme. The second scheme (called the horseshoe scheme, Figure 2) created a channel on the Long Beach side which did not match the orientation of the channel on the Los Angeles side. This channel was better protected from wave forces than the island scheme, where ships would have to be berthed along the exposed southerly boundary.

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Since environmental and political pressures were being put on the Port of Long Beach to adopt the island scheme, the Port felt it was necessary to adequately study potential ship motion problems with this configuration. Specifically, the Port wanted to study if it was feasible to berth ships along the southerly boundary line of the island scheme configuration. This area would not have the double breakwater protection afforded most berths in the harbors today, but would only be protected by the federal breakwater from exposure to wave forces.

While not experiencing catastrophic ship motion problems in the Port of Long Beach area, the Port has had a history of minor ship motion problems in its southeast basin. These problems have had a minimal effect on ship loading and unloading efficiencies in the past. The Port's governing criteria in all future developments was to attempt to create no new facilities which would have any potentially greater ship motion problems than those which already exist, and to make sure that any new development does not increase the ship motion problems in any existing facility.

The type of cargo anticipated to be handled at the new landfill was a key issue in studying any potential ship motion problem. Liquid bulk ships, for example, can tolerate a great deal of ship motion, since the main governing criteria is the strength of the mooring lines and the flexibility of the unloading arms. Container ships, on the other hand, have very tight tolerances, since the container crane must be able to pick up a container off the ship with very limited clearances. Unfortunately, the cargo projection in the 2020 Plan indicated that by far the greatest growth in cargo tonnage in the future would be in the container-handling area.

In order to adequately address this potential problem and help decide between the two landfill configuration schemes, the Port contracted with Tetra Tech, Inc., of Pasadena, California, to study a range of ships located along the southerly boundary of the island scheme in two different phases of development. The first phase, shown in Figure 1, was before any landfill will be constructed outside the federal breakwater. The second scheme, shown in Figure 2, was after landfill had been constructed south of the federal breakwater and would probably afford a greater level of protection to the southerly boundary of the island scheme.

While the Port contracted for Tetra Tech to analyze a range of ships, it was anticipated that container ships would be the governing factor, for the reasons listed above.

Environmental Conditions at the Project Site

The environmental conditions associated with ship motion and mooring analyses for this project are discussed in the following sections. These conditions basically include wind, wave, and current statistics over the project site as shown in Figure 3. Based on the derived statistics, a set of design criteria of these environmental conditions were determined for ship motion and mooring analyses.

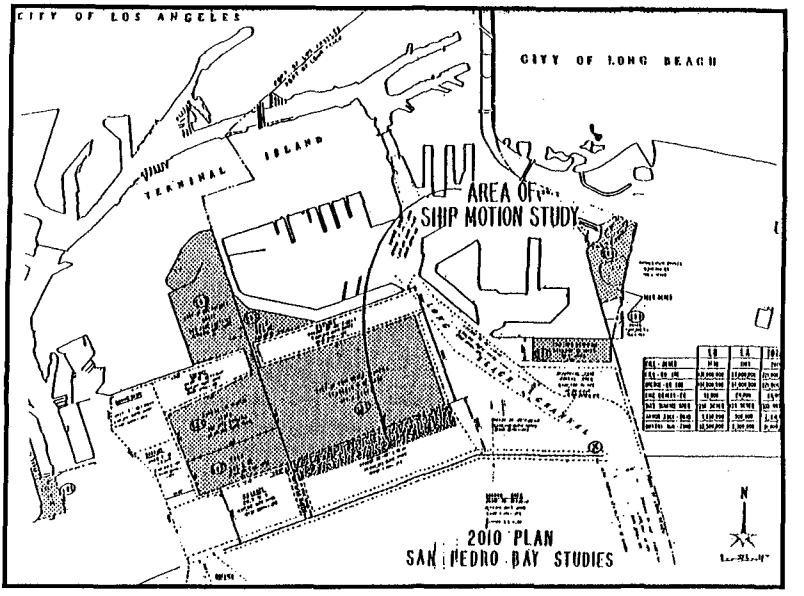

Figure 1 2010 Plan - San Pedro Bay Studies

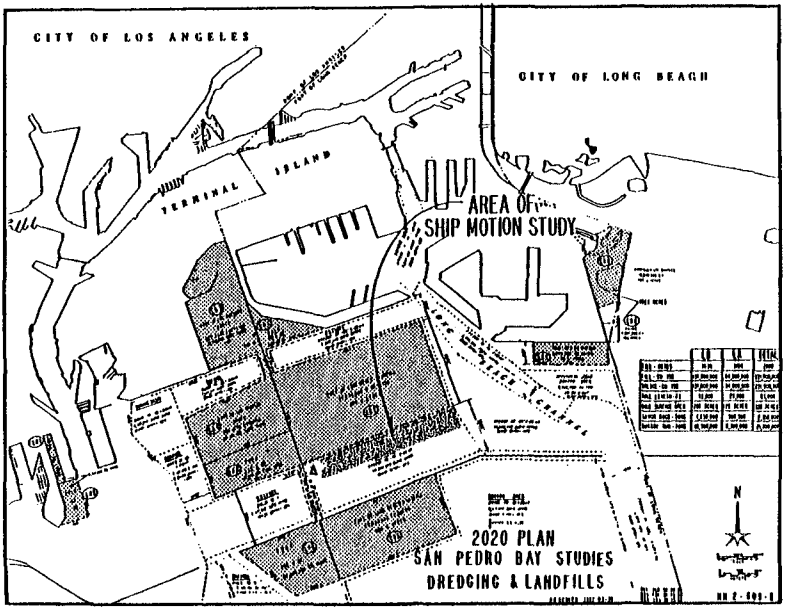

Figure 2 2020 Plan - San Pedro Bay Studies - Dredging and Landfills

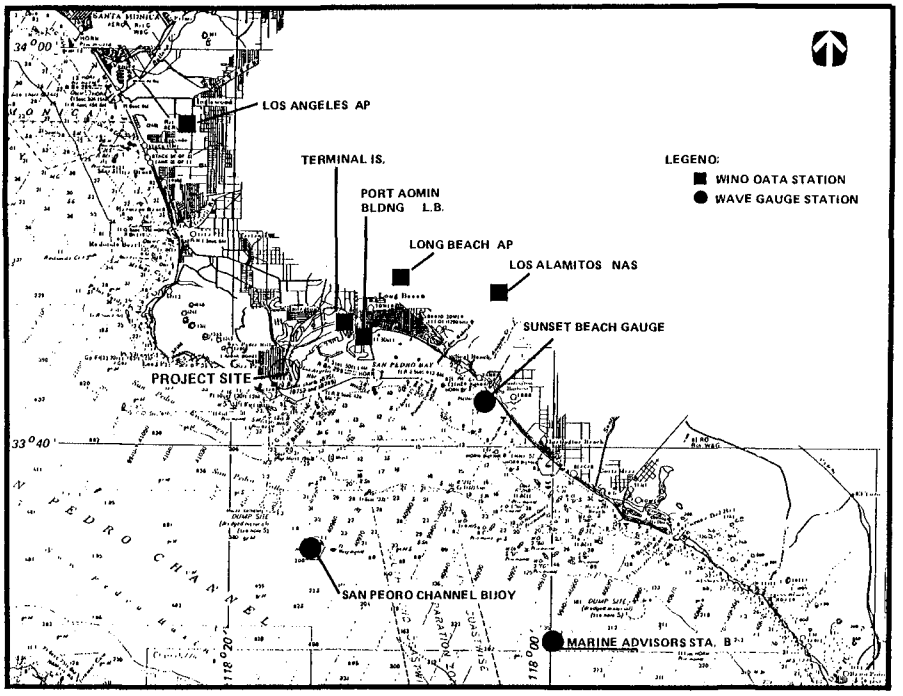

Figure 3 Wind and Wave Gauge Locations

Winds

According to Tetra Tech's previous studies associated with Los Angeles and Long Beach Harbors (Tetra Tech Report TC-3817, 1984), numerous wind information was reviewed and the most applicable wind statistics were discussed and summarized. Stations with available wind data which are used in this analysis are as follows:

	Station Name	Period of Record	Length of Record (Year)
1.	Terminal Island	1955-1977	23
2.	Long Beach AP	1959-1976	18
3.	Los Alamitos NAS	1950-1968	19
4.	Los Angeles AP	1951-1976	26
5.	Port Admin. Bldg. (Long Beach)	1975-1983	9

The locations of these wind stations are shown on Figure 3.

Based on the partial and annual series associated with the ranking of the selected large events and yearly maximum events, respectively, the return periods of the extreme wind speeds were analyzed. The statistics of Terminal Island were selected for study. This is primarily due to

its twenty-three year record and its location within the close proximity of the project site. The estimates of extreme winds, adjusted to an over-water, one-hour duration average from Terminal Island, are 38, 44, 53, and 61 MPH corresponding to 10, 20, 50, and 100 years return period, respectively. The other set of wind statistics derived from 9-year data of Long Beach Port Administration Building are 37, 40, 45, and 48 MPH corresponding to 10, 20, 50, and 100 years return period, respectively. These results have excellent comparison from those of Terminal Island for 10 and 20 year return period. However, it seems to be under estimated for 50 and 100 year return period due to its relatively short duration of wind record. In the ship mooring analysis, the following wind conditions, corresponding to the 60-second duration gust with 5-year return period, were used:

(i) SW wind of 34 knots
(ii) NW wind of 34 knots

Waves

The project site is relatively well protected from wave attack except the direction from south-southeast through south-southwest. Waves with 30 second periods or larger will propagate into the harbor area through the Gulf of Santa Catalina without encountering any effective natural barriers. Whereas the waves with the period less than 30 seconds will experience the effects of wave refraction and island sheltering. The data source of extreme wave condition includes direct measurement inside San Pedro Bay and transformation of hindcasted waves from deep water to the project site.

The relatively short period (less than 30 seconds) extreme waves were associated with major storms or extreme winds. This wave information was obtained by performing deep water wave hindcasting of the selected most severe ten cases during approximately 50 years (IRC, 1976). These deep water waves were transferred into the project site by considering the effects of wave refraction, shoaling, and island sheltering (Tetra Tech Report TC-3817, 1984). Table 1 presents the wave statistics in deep water and in the vicinity outside the breakwater. A 1.7-foot wave height, corresponding to a return period of 1 year, was selected as the representative wave height that would be encountered during daily operations. The transmission coefficient for waves penetrating through the breakwater was adjusted for waves with periods shorter than 16 seconds. Table 2 presents the estimated short period waves, which were used to simulate the ship motions under normal conditions, at the project site of 2010 Plan and 2020 Plan.

Table 1
Wave Statistics in Deep Water and Gate Entrance

Return Period (Yr)	H_{max} (ft, Deep Water)	H_{max} (ft, Gate Entrance)
10	32.8	14.8
20	39.3	19.7
50	45.9	29.5
100	52.5	39.4

Table 2
Estimates of Short Period Waves - Project Site (1-Year Return Period)

Wave Period (sec)	Wave Height (ft)
6	1.1
8	1.3
10	1.4
12 - 14	1.6
16 - 22	1.7

Note: Assume 0.3 transmission coefficient for the waves penetrating through the breakwater.

The characteristics of relatively long period waves (larger than 30 seconds) were measured at Angel's Gate and Queen's Gate during the year of 1971-1972. The long wave statistics are almost impossible to be estimated due to their very limited measurement duration. However, the maximum energy level was measured and the corresponding maximum wave height was estimated by spectral analysis. Wave data were measured by Bottin and Outlaw (1984) at certain locations for the existing conditions. Under the 2010/2020 landfill plans, the wave environment is different from the existing condition. A numerical model was applied to determine the wave environment for the proposed plan. The numerical model geometry and their 290 x 140 grid points for the 2010 and 2020 Plan is shown in Figures 4 and 5, respectively. The maximum long wave heights at the project site were estimated by applying the response factor obtained from the results of the numerical model. Table 3 summarizes the estimated maximum long period wave height at Queen's Gate and the project site of the 2010 and 2020 Plan.

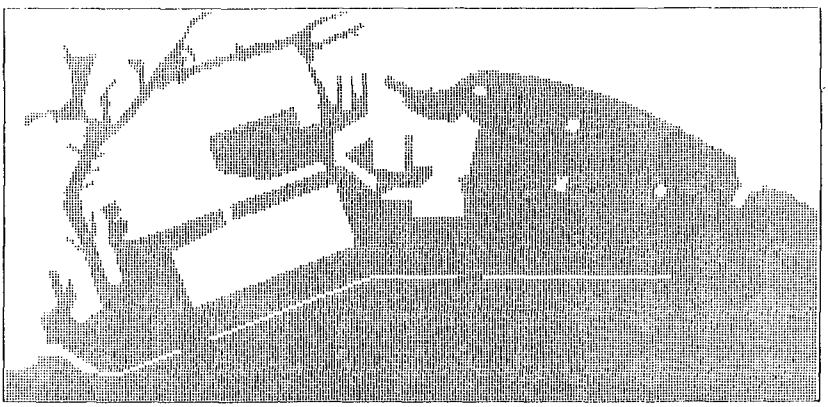

Figure 4 Grid Points in the Numerical Model for 2010 Plan

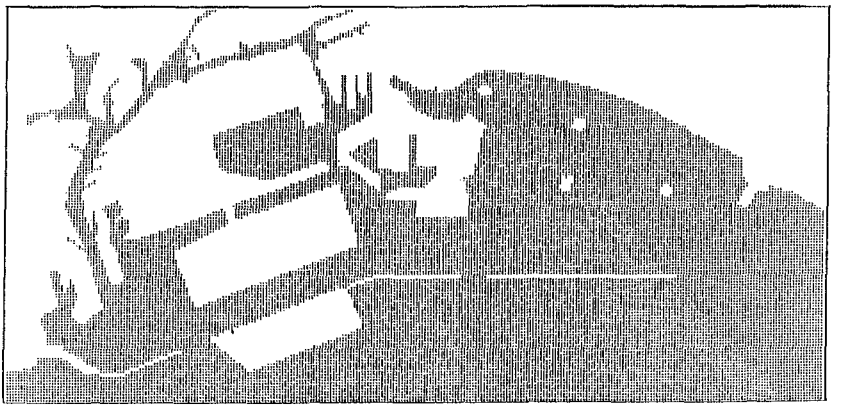

Figure 5 Grid Points in the Numerical Model for 2020 Plan

Table 3
Estimates of Maximum Long Wave Height

Wave Period (sec)	Wave Height (ft) Queen's Gate	Wave Height (ft) 2010 Plan	Wave Height (ft) 2020 Plan
30	0.09	0.30	0.30
40	0.07	0.25	0.25
50	0.05	0.20	0.20
60-70	0.04	0.15	0.10
80-100	0.03	0.15	0.10
110-140	0.02	0.10	0.05
150-180	0.02	0.08	0.08
190-210	0.01	0.10	0.10
220-230	0.01	0.05	0.05
240-300	0.01	0.03	0.03

In order to perform a downtime analysis of the ships, the wave data base in the vicinity outside the breakwater was established by transferring deep water waves to the shallow water site. The deep water waves were obtained from the Sea-State Engineering Analysis System which is maintained by the U.S. Army Engineer Waterways Experiment Station. The joint occurrence probabilities (%) of wave height and period near the breakwater are presented in Table 4.

Table 4
Occurrence Probability (%) of Wave Height and Period
Los Angeles-Long Beach Breakwaters

	Period(s)								
Height (ft)	4.4-6.0	6.1-8.0	8.1-9.5	9.6-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	18.2-22.2
0.0- 3.2	5.78	20.58	15.23	10.68	14.65	14.25	1.37	0.03	0.01
3.3- 6.5	0.03	0.19	0.49	0.36	0.85	2.91	9.03	0.56	--
6.6- 9.7	0.02	0.07	0.08	0.08	0.14	0.44	0.73	0.94	--
9.8-13.0	--	0.02	0.03	0.02	0.01	0.03	0.26	0.02	--
13.1-16.3	--	0.01	0.04	0.01	--	0.02	--	0.01	--

Currents

The maximum tidal current measured at the project site is approximately 0.5 ft/sec. It is believed that this tidal current should have the least impact on the ship motion and mooring analyses.

Ship Motion and Mooring Analysis

Three representative ships, the D-9 class container ship, 265,000 DWT tanker, and 100,000 DWT dry-bulk carrier, that will frequent the project site of the 2010 Plan and 2020 Plan of the Port of Long Beach, were considered in the study. The principal particulars of these ships are presented in Table 5.

Table 5
Principal Particulars of the "Representative" Container Ship, Tanker, and Dry-Bulk Carrier

Principal Particulars	D-9 Class Container Ship	265,000 DWT Oil Tanker	100,000 DWT Dry-Bulk Carrier
Length Overall (ft)	745	1100	886
Length between Perpendiculars (ft)	699	1060	853
Beam (ft)	100	178	138
Depth (ft)	54	86	69
Draft (ft)	31	67	49

Several mooring configurations, some consisting of steel lines, some dacron lines, and some of a combination of steel and dacron lines, were used to evaluate the ship response under imposed environmental conditions. A typical mooring configuration for the D-9 class container ship is shown in Figure 6. Vessel and berth characteristics, loading condition, mooring line arrangement, fender system, and the excitation force were the input parameters for the Tetra Tech six-degree ship motion analysis program. The detailed description of this numerical solution procedure can be found in the reference report.

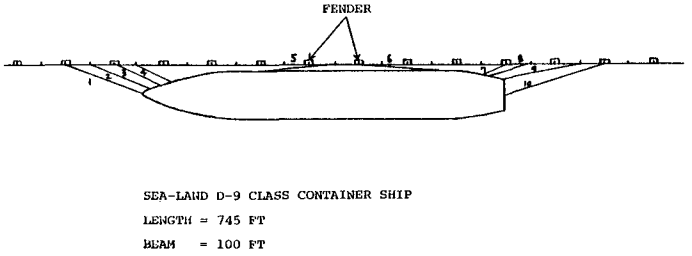

Figure 6 Mooring Line Arrangement - D-9 Class Container Ship Dacron and Steel Lines

Summary of Ship Motion Analysis Results

The primary direction of wave approach was assumed to be zero degree from the stern of the moored ship. It was anticipated that this wave approach angle should provide the information on the maximum longitudinal motion, the surge. For the D-9 class container ship, 265,000 DWT tanker, and 100,000 DWT dry-bulk carrier, ship responses were computed as a function of the wave period and wave wave height as established in Table 3. Only the summary of the results of the maximum surge amplitude for the container ship, tanker and dry-bulk carrier are presented in Table 6. The fender force, hull pressure, and line load under various mooring conditions were determined. The typical line loads due to wave force, wind force, and combination of wave and wind force for a typical case are presented in Table 7.

Table 6
Summary of Maximum Surge Amplitudes

Ship	Plan	Maximum Surge Amplitude (ft)	Mooring Lines	Resonant Wave Period (sec)
Container (D-9 Class)	2D10	4.41	Dacron	100
		0.73	Steel	30
		2.48	Dacron & Steel	60
	2020	2.02	Dacron	120
		0.73	Steel	30
		1.50	Dacron & Steel	70
Oil Tanker (265,000 DWT)	2010	1.28	Dacron	210
		2.23	Steel	80
	2020	1.28	Dacron	210
		2.09	Steel	80
Dry-Bulk Carrier (100,000 DWT)	2010	2.13	Dacron	190
		0.87	Steel	40
	2020	2.13	Dacron	190
		0.87	Steel	40

Table 7
Line Loads Due to Environmental Forces
D-9 Class Container Ship

Lines	Environmental Force	Maximum Load On Mooring Lines (long tons)									
		1	2	3	4	5	6	7	8	9	10
Dacron & Steel*	60 Sec. wave	40.56	1.76	2.39	4.05	1.36	1.40	6.89	3.38	1.37	31.11
	NW Wind 34kt	20.00	1.90	0.97	1.14	0.09	0.12	6.58	1.88	0.42	19.74
	SW Wind 34kt	9.97	0.44	0.59	1.00	--	0.34	--	--	--	--
	Wave & NW Wind	60.56	3.66	3.36	5.19	1.45	1.52	13.47	5.26	1.79	50.85
Dacron	100 Sec. wave	3.13	4.61	4.61	6.31	10.73	14.37	7.06	4.07	3.04	2.09
	NW Wind 34kt	3.48	5.20	5.20	3.17	4.67	20.91	5.91	2.26	1.27	0.77
	SW Wind 34kt	1.33	1.95	1.95	2.65	4.46	--	--	--	--	--
	Wave & NW Wind	6.61	9.81	9.81	9.48	15.40	35.28	12.97	6.33	4.31	2.86
Steel	30 Sec. Wave	7.63	11.22	1.22	15.03	25.35	34.55	16.70	9.55	6.69	4.88
	NW Wind 34kt	4.84	6.80	6.80	2.76	2.07	19.39	5.70	2.28	1.35	0.85
	SW Wind 34kt	1.33	1.95	1.95	2.65	4.46	--	--	--	--	--
	Wave & NW Wind	12.47	18.02	18.02	17.79	27.42	53.94	22.40	11.83	8.04	5.73

*Note: Steel lines (1 and 10)
Dacron Lines (lines 2 to 9)

Downtime Analysis

Berth downtime is defined as the length of time that the mooring capacity limits are exceeded. The following criteria were considered in establishing the mooring capacity limits:

- o mooring line loads
- o vessel motions
- o fender deflection and hull pressure

Mooring Line Loads

According to the guidelines followed by Butcher et al (1980) an ultimate mooring limit for a particular mooring situation is defined as 65% of the new wire breaking strength. The operating mooring limit, however, is recommended to be equal to the defined ultimate mooring limit divided by a load factor of 1.4 to 1.6. Consequently, 45% of the breaking strength is used as the allowable limit for steel wires. Similarly, the ultimate mooring limit for dacron line is defined as 55% of the breaking strength and 35% of the breaking strength is used as the allowable limit for dacron lines. Line loads in excess of the recommended operating limits are considered excessive and contribute to berth downtime.

Vessel Motions

Oscillatory vessel motions with an amplitude greater than the following limits, in the surge direction, are considered excessive and contribute to berth downtime. The Port of Long Beach provided the following limits for ship surge downtime:

- o Container ships, 0.5 feet of surge
- o Dry-bulk carriers, 5 feet of surge
- o Liquid-bulk carriers, 10 feet of surge

Fender Deflection and Hull Pressure

Hull pressure was taken as the critical condition over fender deflection if excessive lateral motions exist. Consequently, only the allowable hull pressure is checked for downtime analysis. The allowable hull pressure for the three ships considered in the present analysis is listed in the following:

Ship	Maximum Allowable Hull Pressure
D-9 Class Container Ship 265,000 DWT Tanker 100,000 DWT Dry-Bulk Carrier	9.88 long tons/yd^2

Hull pressures greater than these limits are considered excessive and contribute to berth downtime.

Downtime Results

Based upon the calculated results of line loads, vessel motions, and hull pressure presented in the previous section, the vessel downtime can be determined by checking the calculated results with the limiting criteria. The statistics of the short period waves (6-22 seconds) were obtained from Table 4. It should be noted, however, that since there is no data available concerning long period wave ($T > 22$ second) activity in the project sites of the 2010 Plan and 2020 Plan, only vessel response due to waves of periods between 6-22 seconds is considered in the downtime analysis.

Conclusion

Surge is the most significant motion response of the tanker, D-9 Class container ship, and dry-bulk carrier to waves approaching head on (head-sea condition). Since the waves at the project site of Plan 2010 are larger than the waves at the project site of Plan 2020, the ships have larger motion response at Plan 2010. The maximum surge amplitudes of 2.2 and 2.1 feet for the tanker and dry-bulk carrier, respectively, are within the operational limits of surge motion and would not contribute to berth downtime. For the container ship, the mooring system consisting of steel lines induces a smaller maximum surge amplitude than the mooring system consisting of dacron lines, while the mooring system consisting of combination of dacron and steel lines induces a maximum surge amplitude in between of the all steel and all dacron line systems. All the three mooring systems of the container ship result in maximum surge amplitudes larger than 0.5 feet and would contribute to berth downtime. This problem can be mitigated by introducing frictional force between the ship hull and the fender system.

The results of the significant surge amplitude are obtained by letting the ships respond to a spectrum of incoming waves. At the project site of Plan 2010, with the exception of the container ship which is moored by dacron and steel lines, the results of the significant surge amplitude are not smaller than those of the maximum surge amplitude, because the peaks of the ship response spectra sometimes occur close to the peaks of the wave spectra. However, the magnitudes of the significant surge amplitude can be reduced by imposing frictional forces between the ship hull and the fender systems. For instance, the significant surge amplitude of the container ship with the mooring system consisting of dacron and steel lines is redued from 1.96 feet to 1.28 feet when a frictional force of 12,8000 lb is imposed.

For the beam-sea wave conditions, the 1 year waves do not induce significant sway motion or line loads. The maximum fender loads are well within the rated reaction force of the proposed fender. Except for the case of the tanker under high frequency wave conditions (6-7 seconds), the ship hull pressures are also within the maximum allowable hull pressure limit. The problem of excessive hull pressure can be solved by employing additional breast lines to reduce the sway motion during short period beam-sea wave condition. Another solution is to increase the surface area of the fender or the number of fenders.

Tankers and dry-bulk carriers in ballast conditions and container ships in full load condition are more susceptible to wind forces due to the relatively large exposed area above the waterline. Consequently, wind forces are an important factor in regards to mooring safety in the present analysis. Wind forces are higher on the tanker, due to the larger exposed windage areas. The forces induced by the 34kt NW wind load the steel mooring line up to 25%, 25%, and 14% of the line breaking strength for the tanker, D-9 Class container ship, and dry-bulk carrier, respectively. Therefore, the 5-year, 60-second-duration gust does not impose a threat to mooring safety.

Using the wave statistics and the 5-year, 60-second-duration gust wind conditions, the downtime probabilities were calculated to be 0.34, 1.53, and 0% for the tanker, D-9 class, and dry-bulk carrier, respectively.

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