CHAPTER 205

PROBABLE UTILIZATION LEVEL FOR A BARGE HARBOR

Martin T. Czerniak[1]
Choule J. Sonu[2]

INTRODUCTION

The main consideration in harbor master planning is to maximize the amount of time that the harbor can be used. The potential level of harbor utilization can be evaluated by analyzing vessel performance during harbor operations in terms of the range of imposed environmental conditions. The harbor utilization level is expressed statistically as the probable amount of time that the harbor can be used as planned.

In this paper, a siting study for a towboat-barge harbor will be described. This example will demonstrate the use of harbor utilization statistics for a simplified case of a single-purpose harbor and a single design vessel. This scheme can be applied to more complex cases of multipurpose harbors used by a variety of vessels. The purpose of this paper is twofold. First, it outlines the basic concept of harbor utilization statistics and their value to harbor master planning. While it seems that studies of this type would have been undertaken in the past, at present no examples have been found by the authors among published literature. Secondly, considering the lack of published information, it is beneficial to record some practical experience regarding towboat and barge systems as design vessels.

APPLICATION

Many harbor operations can be analyzed using harbor utilization statistics. For example, an evaluation of entrance/exit conditions will lead to utilization statistics that define the percentage of time that vessels can safely negotiate the harbor entrance. The loading/unloading/berthing utilization can also be considered. This calculation would involve the wave height in the berth area of the harbor and may influence harbor configuration by revealing the need for additional breakwater sections (LeMehaute, 1976). A "harbor-of-refuge" can be better planned to provide safe entrance and safe mooring during storms if utilization statistics are compiled for the types of small craft generally found in nearby waters.

Harbor utilization statistics can be interpreted in terms of the economic and functional feasibility of a specific harbor configuration, location, and operational plan. The computations will reveal how harbor utilization can be improved by plan modifications. Economic analyses are improved because the benefits attributable to the harbor's presence can be more accurately established.

[1]Senior Engineer and [2]Principal Engineer,
Tetra Tech, Inc., Pasadena, California, U.S.A.

PROCEDURE

Once the design vessels and the intended purpose of the harbor have been decided, three steps are necessary to determine the utilization level of a particular harbor operation:

(1) Identify the environmental parameters which influence vessel behavior during the harbor operation of interest;

(2) Determine the "critical level" of each parameter beyond which safe operations are jeopardized;

(3) Determine the probable amount of time that the harbor will be closed due to the exceedance or joint exceedance of the "critical levels."

Often the occurrence statistics for the important parameters that are identified in step 1 will not be directly available from environmental data summaries. In such cases, appropriate engineering analyses must be employed to develop the needed data from the available statistics. For example, if it has been determined (step 2) that the maximum allowable wave height in the berth area of a proposed harbor is 40 cm, then refraction and diffraction techniques must be used to establish all the incident wave conditions that will result in this wave height there. Once these conditions are known, data summaries of incident wave height, period and direction can be used to establish the probability of exceeding the allowable wave agitation in the berth area (step 3).

EXAMPLE: TOWBOAT - BARGE HARBOR

Harbor utilization statistics were used to select the best site during the master planning of a proposed harbor for the central California coast. The proposed harbor must provide year round safe entrance and unloading conditions for barges in order to maintain the delivery schedule of construction materials for the development of the Vandenburg Air Force Base. Due to the nature of the coastline, a "shoreline harbor" is required. That is, primary harbor protection is provided by breakwaters, and the harbor basin is located seaward of the existing shoreline. The vessels that will be used for the delivery operation are ocean-going towboats, which commonly draw about 4.5 meters, connected by a towing cable to a medium-sized commercial barge. These barges are about 115 meters long, 25 meters wide, and have a loaded draft of about 4 meters when not ballasted with sea water.

Step 1: Identify Parameters: Three parameters are judged most important in defining the amount of time that the towboat-barge system can safely enter the harbor: (1) the wave height one to four kilometers offshore of the harbor entrance, (2) the wind speed, and (3) the visibility level.

The procedure used by the vessel in approaching and entering the harbor must be known in order to judge which oceanographic and meteorological factors are most important to safety. While underway on the open ocean, about 500 meters of towing cable connect the towboat and the barge (Brady, 1967). As shown in Figure 1a, the tow cable takes a catenary shape and functions as a "spring" to absorb the ship motions of both vessels. Generally, the barge will be ballasted during ocean towing, which helps to reduce its amplitude of response to the waves. Prior to entering the harbor, perhaps one to four kilometers offshore of the harbor entrance, the cable must be shortened for better towing control and the barge must be deballasted of sea water to reduce its draft. In this condition (Figure 1b), the spring action provided by the cable is considerably reduced and the cable could be in danger of parting if the towboat and barge do not ride the wave synchronously. Now deballasted, the barge will respond more to the wave action than it will under ocean-going conditions thus increasing tension in the cable.

The likelihood of a navigational mishap is highest during this period of approach to the harbor. High wave heights during the time when the tow cable is shortened and the barge deballasted may cause the cable to part or the barge to capsize. High winds may make the barge difficult to control while towing, especially if the cargo is bulky and presents a large "sail" area. For the proposed harbor, the vessels must come broadside to the predominant wind direction in order to enter the harbor. Thus, with the slower vessel speed necessary near the harbor, high wind speeds may cause the barge to drift from the course set by the towboat and strike the breakwater or other vessels. Poor visibility is especially hazardous in this case because dense fog is common along the central California coast. No electronic vessel traffic guidance system will be available at the harbor, a condition which when coupled with the rugged wave climate and brisk winds, makes the safe transit of a towed barge into an open-coast harbor quite dependent upon good visibility.

Breaker conditions are not included among the factors influencing the harbor entrance utilization level. By proper planning it is possible to locate the harbor entrance at a depth such that the occurrence of breaker conditions alone would not close the harbor. Two cases must be considered in this planning. First, when the sea state is too high to permit the vessels to safely execute their harbor approach procedures, they must lay off the coast until conditions are more favorable. In this case, the occurrence of high offshore waves effectively closes the harbor to the towboat and barge traffic and it does not matter if the waves are breaking across the harbor entrance. In the second case, the sea state is low enough to permit a normal approach to the harbor and the location of the breaker zone with respect to the harbor entrance is important. For maximum utilization, the harbor entrance should be negotiable by vessels under any wave conditions that the harbor can be safely approached. In this study the minimum depth for the outer breakwaters defining the harbor entrance was taken to be the breaker depth for the highest 2% of the waves in the Rayleigh distribution for the maximum sea state defining the limit of safe vessel approach procedures.

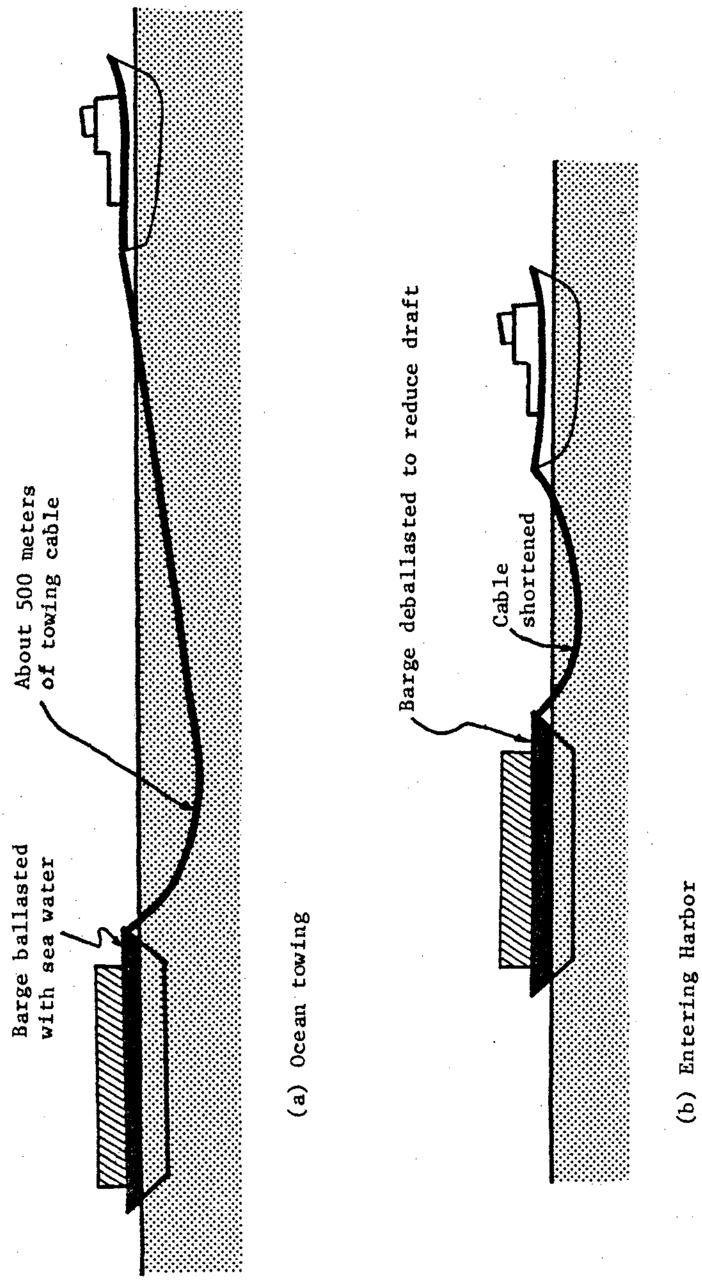

Figure 1: Towing Conditions a) under open ocean towing, and b) while entering the harbor

Step 2: Critical Levels: The critical values of offshore wave height, wind speed, and visibility beyond which safe navigation is jeopardized depends upon the vessel size and type, the operational procedures, and the acceptable risk. Due to the lack of published data on critical levels vis-a-vis design vessels, the harbor engineer must analytically determine them or rely on experienced advice and judgment in selecting them.

An analytical determination of the actual critical wave height for safe operation of the towboat-barge system would require knowledge of the cable-breaking conditions and the risk probability of collision and grounding as a function of wave agitation and vessel response. Such an analysis is costly and time-consuming, and for this reason towboat operators familiar with the central California coast were consulted. While commercial barges commonly operate successfully during offshore wave heights of about three meters (John Turner, personal communication), harbor entrance procedures involving barge deballasting and the shortening of the tow wire require a calmer sea state. Thus, the critical values defining safe navigation were judged to be:

- Critical wave height, H_c = 2 meters
- Critical wind speed, U_c = 20 knots
- Critical visibility level, V_c = 1/4 mile

Although some level of operational risk is implicit in selecting "critical levels," the actual risk will, in fact, vary on a case-by-case basis for each vessel transit into the harbor. This is caused by variables which cannot be realistically considered such as the experience and judgment of the towboat captain and the condition of the equipment.

Step 3: Exceedance Statistics: The harbor cannot be entered safely by the towboat and barge when one or more of the three governing environmental parameters exceed the critical level. The equation which expresses the expected amount of time that the harbor will be closed, P(closure), is:

$$P(\text{closure}) = \underset{(1)}{P(H_c)} + \underset{(2)}{P(U_c)} + \underset{(3)}{P(V_c)} - \underset{(4)}{P(H_c,U_c)} - \underset{(5)}{P(H_c,V_c)} - \underset{(6)}{P(U_c,V_c)} + \underset{(7)}{P(H_c,U_c,V_c)}$$

In this equation, all the terms on the right side express the probability of occurrence or joint occurrence of environmental conditions more severe than those which are safe for navigation. As such, $P(H_c)$ indicates the probability that the wave height exceeds the critical wave height, $P(V_c)$ indicates the probability that the visibility is worse than the critical visibility, and $P(H_c,U_c)$ indicates the probability that both the critical wave height and critical wind speed are exceeded.

The first three terms of the P(closure) equation are determined from cumulative probability distribution plots of the data. Since the probability of the joint occurrence of high waves and high winds is significant, term (4) of the P(closure) equation must be evaluated. This value can be evaluated using a joint exceedance probability plot, as shown in Figure 2 for the January statistics in the study area. Using this figure, the probability that winds greater than 20 knots and offshore waves higher than 2 meters occur simultaneously is 5.5%.

In the study area, most events of poor visibility are caused by fog or haze. Intuitively then, it would seem that poor visibility would be largely a calm weather phenomenon, not occurring when wind speed and wave heights are high. An evaluation of the available data showed this to be true more than 99.9% of the time. In practical usage, therefore, events of high wind or high waves are mutually exclusive of events of poor visibility in this area, causing terms (5), (6), and (7) to drop out of the P(closure) equation.

Results: With P(closure) determined by an evaluation of terms (1), (2), (3) and (4), the harbor utilization is solved by 1-P(closure). For the example problem, harbor utilization statistics were compiled for two potential harbor sites using data supplied by the U. S. Air Force and by the Summary of Synoptic Meteorological Observations (SSMO). The results are given in Table 1 and plotted by month in Figure 3. Note that site A would provide a higher overall harbor utilization level, but that the two sites differ markedly in the probability of supercritical conditions for each of the three important parameters. These differences are consistent with the varying site conditions, including coastal exposure, air flow patterns and local shoreline topography. This example illustrates how harbor utilization statistics help provide a rational comparison among potential harbor sites which possess counterbalancing siting characteristics. Harbor utilization can be improved over the level shown in Figure 3 by the selection of larger design vessels which can safely operate under more severe environmental conditions.

ECONOMIC IMPLICATIONS

When monetary values are assigned to harbor operational time and harbor down time, the harbor utilization concept provides a basis for a rational comparison of harbor costs and benefits. As an evaluation of berthing and unloading conditions may indicate that one potential harbor site requires more breakwater sections than another in order to achieve the same utilization level, the relative construction costs are also indicated.

The economic feasibility of harbor protection by breakwaters can also be addressed. For example, consider Figure 4 which shows the annual cumulative probability distribution of wave heights at a potential harbor site. Table 2 summarizes the various navigation conditions which ships using the harbor would encounter and the probability of occurrence of each condition based on the wave statistics given in Figure 4. The

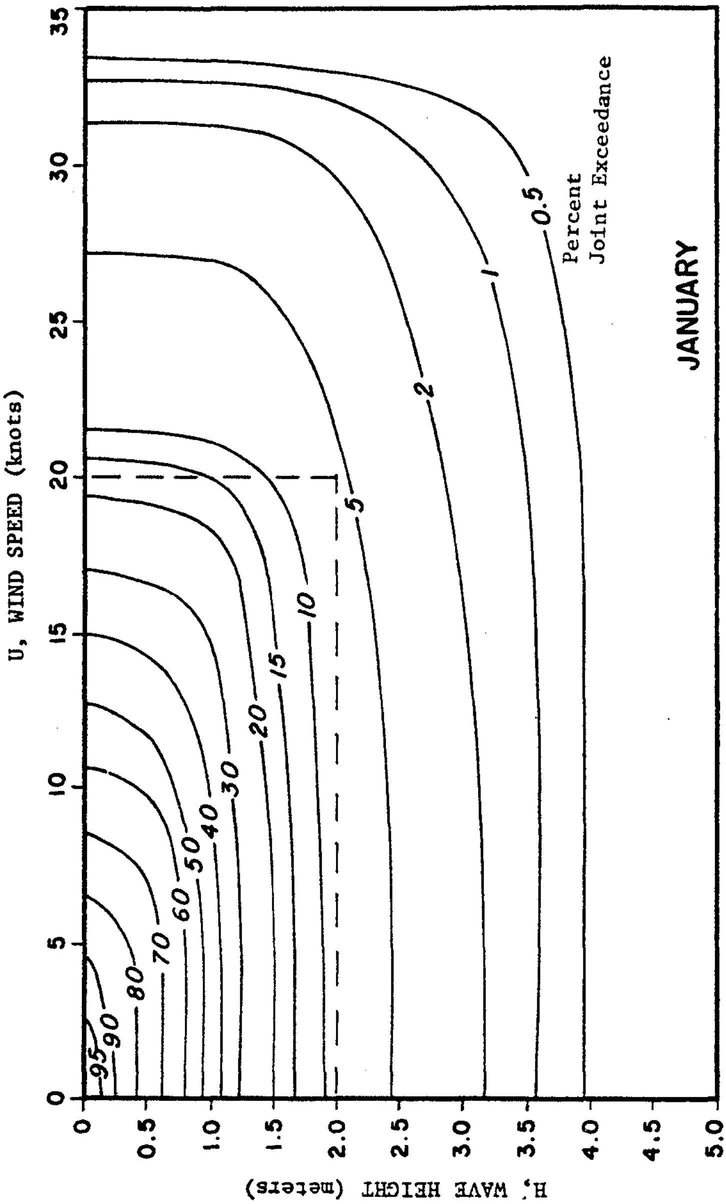

Figure 2: Joint Exceedance Probability (in percent) for Wave Heights and Wind Speeds. (Intersection of dashed lines indicates that the percent joint exceedance of wind speeds >20 knots and wave heights >2.0 meters is 5.5%).

Table 1

HARBOR ENTRANCE UTILIZATION STATISTICS
FOR TWO POTENTIAL HARBOR SITES

Month	Percent of Time Harbor Is Closed by Factor					Harbor Utilization Level
	Visibility P(V<1/4 mi)	Offshore Wave Height P(H>2 m)	Wind Speed P(U≥20 kts)	Correction for Joint Occurrence P(H>2,U>20)	Total Percent Nonoperational Time P(closure)	(Percent Operational Time)
			Site A			
JAN.	2.0	9.6	0.3	5.5	6.4	93.6
FEB.	2.8	14.5	0.9	6.1	12.1	87.9
MAR.	3.3	18.0	1.5	8.8	14.0	86.0
APR.	2.7	20.3	1.7	12.5	12.2	87.8
MAY	4.9	22.2	0.7	15.0	12.8	87.2
JUNE	7.4	18.6	0.9	13.0	13.9	86.1
JULY	12.5	13.0	0.1	8.4	17.2	82.8
ADG.	12.8	13.6	0.1	5.7	20.8	79.2
SEPT.	9.7	6.5	0.3	4.7	11.8	88.2
OCT.	7.5	10.8	0.8	5.9	13.2	86.8
NOV.	3.7	12.4	0.4	4.8	11.7	88.3
DEC.	2.9	16.3	1.0	6.6	13.6	86.4
			Site B			
JAN.	1.1	14.6	11.0	5.5	21.2	78.8
FEB.	2.0	5.0	15.1	6.1	16.0	84.0
MAR.	0.9	10.0	20.5	8.8	22.6	77.4
APR.	1.1	10.0	19.6	12.5	18.2	81.8
MAY	2.1	6.2	22.3	15.0	15.6	84.4
JUNE	1.4	9.3	32.9	13.0	30.6	69.4
JULY	1.7	1.7	24.0	8.4	19.0	81.0
AUG.	2.3	6.6	29.7	5.7	32.9	67.1
SEPT.	2.2	4.3	27.2	4.7	29.0	71.0
OCT.	2.8	4.2	16.7	5.9	17.8	82.2
NOV.	2.2	11.7	10.9	4.8	20.0	80.0
DEC.	1.5	9.7	14.0	6.6	18.6	81.4

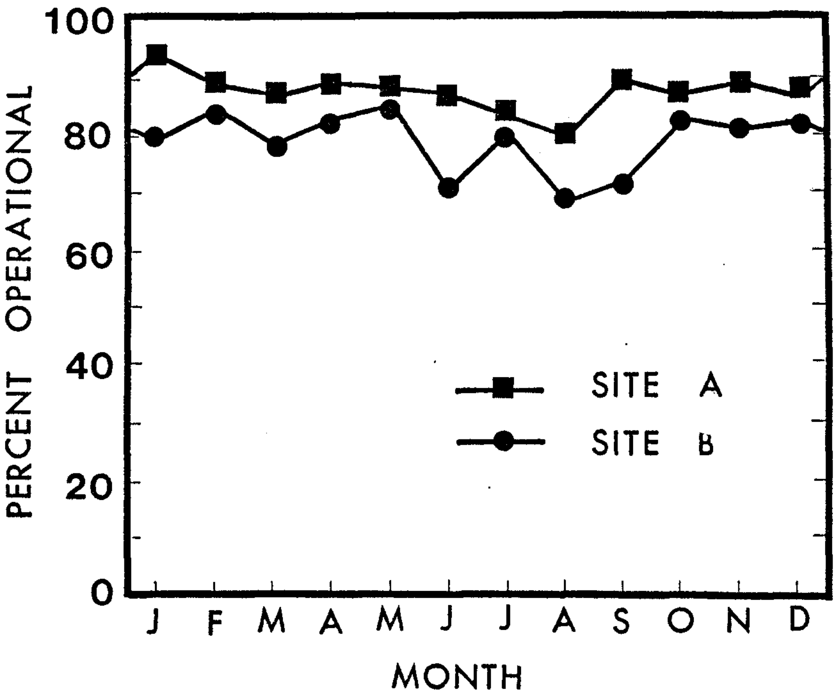

Figure 3: Harbor Entrance Utilization Level by Towboat-Barge Systems for Two Alternate Harbor Sites (for wave height >2 meters, wind speeds >20 knots, and visibility <1/4 mile).

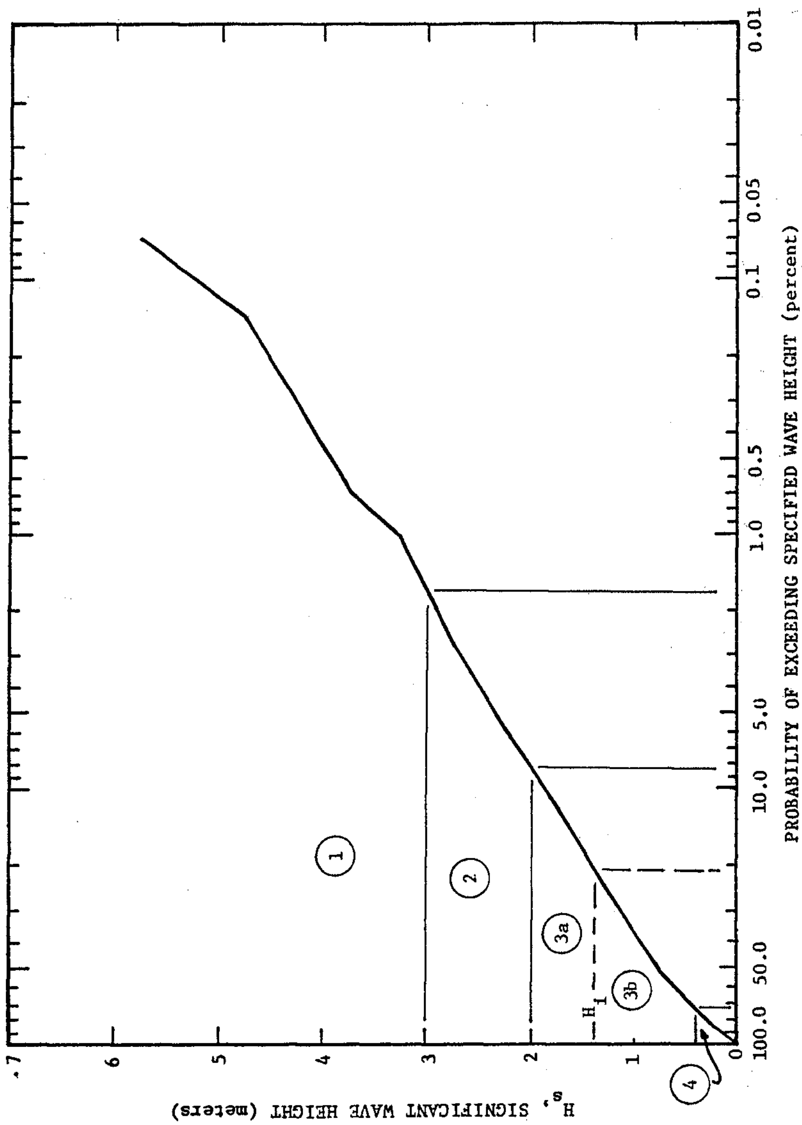

Figure 4: Annual Probability Distribution of Waves at a Potential Harbor Site Showing Range of Navigational Conditions Experienced by Approaching Ships

Table 2

DESCRIPTION AND PROBABILITY OF OCCURRENCE OF NAVIGATIONAL CONDITIONS

Condition	Description	Incident Wave Height Outside Harbor (meters)	Annual Probability of Occurrence (percent)
1	Sea traffic not possible	$H>3$	1.6
2	Sea traffic possible, but cannot safely enter harbor	$3>H>2$	6.4
3a	Ships can enter harbor but cannot safely unload cargo	$2>H>H_i$	67.0
3b	Ships can unload cargo in sheltered harbor area, but could not unload without protection of breakwater	$H_i>H>0.4$	
4	Ships can unload cargo even without shelter of breakwater	$0.4>H>0$	25.0

allowable wave height for unloading depends upon the particular cargo, the method of unloading, the type of ship being unloaded, and the location of stowage aboard ship. If the allowable wave height in the berth area is 40 cm for a particular set of unloading conditions, then there exists an incident wave height outside the harbor, H_i, which after transformation will result in the 40 cm wave in the harbor. For incident wave heights between 0.4 and H_i meters, breakwater protection is required to unload the cargo (condition 3b in Table 2). For incident wave heights between H_i and 2 meters, the ships can safely enter the harbor, but cannot unload because wave heights at the berth will be greater than 40 cm (condition 3a). For maximum harbor utilization, therefore, it is clear that the harbor should be designed so that ships can unload any time that they can safely enter the harbor.

During condition 4, the breakwater is not needed at all, and the ships can unload while moored at a pier or quay. Under conditions 1 and 2, the harbor cannot be utilized, no matter how well designed and situated. Only during condition 3 is the cost of the breakwater being converted usefully into increased harbor operating time.

SUMMARY

A method of determining the probable amount of time that a harbor will be operational has been outlined. This method requires the harbor engineer to evaluate vessel performance capabilities in terms of environmental parameters. These "harbor utilization statistics" are a valuable tool for harbor master planning because they provide a rational means of comparing alternate harbor sites in terms of their functional and economic feasibility.

The use of harbor utilization statistics has been illustrated herein by a study to site a barge harbor along the central California coast. Although this example provides a simplified case of a single-purpose harbor and a single design vessel, the scheme should provide valuable results for a number of other harbor studies:

- Safety analysis of harbors for the shipment or receiving of hazardous cargoes.
- Improved planning and design of small "harbors-of-refuge" in terms of safe entrance, anchorage, and berthing during storms of various intensities and for the various types of small craft generally found in nearby waters.
- Rational harbor site selection among alternative locations having counterbalancing beneficial and detrimental characteristics.
- More realistic economic analyses of costs and benefits of harbor construction.

ACKNOWLEDGMENTS

The study reported on in this paper was performed for the U. S. Department of the Air Force, Space and Missile Systems Organization, Los Angeles. The authors appreciate their cooperation and the meteorological data provided by them. The authors also appreciate the valuable suggestions made by Bernard LeMehaute and Raymond Rodrigue of Tetra Tech during the course of this study and the editorial suggestions of Allene S. Czerniak.

REFERENCES

1. Brady, Edward M. (1967), Tugs, Towboats, and Towing, Cornell Maritime Press, Inc., Cambridge, Maryland, 256 p.

2. LeMehaute, Bernard (1976), "Wave Agitation Criteria for Harbors," Proceedings, 15th International Coastal Engineering Conference.

3. Turner, John J., President of Pacific Towboat and Salvage Company, Long Beach, California.