PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
TECHNICAL UNIVERSITY OF NORWAY

OFFSHORE TANKER LOADING IN THE NORTH SEA

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The offshore petroleum industry has, over the past 20 years, ventured further and further out into greater water depths to search for the new reserves needed in our energy hungry age. The early discoveries offshore were in shallow or protected waters where it was relatively easy to move the gas and oil to shore in pipelines and barges. In recent years the industry has found oil in the deep waters off California, in the icy waters of Cook Inlet in Alaska with its swift moving tides and drifting ice, in the choppy waters of Bass Strait off Australia, but all still fairly close to shore.

Now oil and gas have been found in the North Sea, famous for its sudden storms and rough waters. Many of the discoveries made by the Phillips Group and others have been near the geographical center of the North Sea, nearly 200 miles from the nearest shore line. The closest landfall to our discoveries is the southern Norwegian coast, but this is separated from the oil fields by the formidable Norwegian trench, a scar in the sea bottom reaching a depth of 1000 feet along the shortest pipeline routes. In some places the trench has rock outcroppings with steep slopes. The construction and operation of a pipeline in these changeable waters and great depths would tax the limits of commercially available construction, maintenance and diving equipment.

These distant offshore discoveries naturally touched off an intensive search for new ideas or new applications of proven ideas to find economical ways of moving the oil to markets. Many studies are being made to investigate thoroughly the technical and economic feasibility of laying pipelines to shore. The studies so far have indicated that there may be several years of development time involved to produce the techniques and equipment needed to build and maintain a pipeline successfully. At the same time that these studies were started Phillips began studying ways of loading the crude oil offshore at the field location in order to begin production as early as possible and gain some operating experience.

During the last decade with the advent of super tankers requiring water depths greater than those available in conventional ports, there has been an increasing use of offshore mooring and cargo handling facilities. Several types of facility have been developed and used, including fixed platforms or docks with breasting dolphins, multi-buoy berths and several variations of single point mooring buoys. Other structures such as artificial islands and harbors and floating or fixed breakwaters have been proposed, but their use has been limited because of the high cost and uncertainty about performance in the open sea.

To determine whether crude oil tanker loading could be accomplished at the center of the North Sea, and, if so, the optimum method and equipment required, Phillips conducted a study which covered several areas.

A wind, wave and current study for the location was obtained from a professional meteorologist and oceanographer. Data from 3 years of hourly weather observations from one of our drilling rigs in the North Sea were computer analyzed and correlated with the professional study. Tanker scheduling and loading was simulated on the computer.

A literature and patent search on breakwaters, floating harbors and offshore tanker loading systems was conducted. Schemes proposed by various outside engineering firms and engineers, as well as some of our own, were considered. Suppliers of "conventional" offshore tanker loading equipment were consulted. Suggestions and opinions were solicited from shipping companies and experienced tanker captains. We also considered our own experience as well as that of other operators loading tankers offshore.

From this study we were able to reach certain conclusions, the principle one being that we considered offshore loading of tankers at the Ekofisk location to be possible with properly designed equipment, but that any of the methods considered would experience some downtime due to weather. The downtime was considered to be acceptable as part of a test program in extreme offshore operations before committing ourselves to more permanent facilities.

The various ideas studied can be grouped as follows:
A. Breakwaters or Artificial Harbors - These include artificial islands, artificial harbors, floating breakwaters, perforated breakwaters and artificial beaches. The number of ideas which have been patented in the last few years is impressive. However, none of these was considered feasible in the open sea at Ekofisk location because of navigational problems, insufficient operating experience, long construction times and extremely high costs in the 235 foot water depth.

B. Multiple Point Mooring System - This consists of a series of buoys anchored to the bottom and oriented in the direction of prevailing wind and waves. The tanker ties up with the assistance of her own anchors and a mooring launch. When in position she picks up a loading hose either from the bottom or from a fixed structure nearby. This system requires a longer time to moor and unmoor and is limited to relatively calm water and locations where wind and waves are consistently from one direction. The weather data studies for the Ekofisk location show that the wind and seas approach nearly equally from all directions, making a multiple buoy system impractical. (See Figure 1).

C. Single Point Mooring System - To solve the problem of mooring and loading in more exposed locations, the single point mooring system has been developed. This is a large buoy (or in a few cases a fixed structure) anchored to the sea bottom and fitted with a turntable which allows 360 degree rotation of the mooring point and surface loading hose. This allows the tanker to approach and tie up regardless of the direction of wind and wave. Since the tanker is moored at the bow only, it is free to swing with changes in wind and waves so that mooring forces are at a minimum and it is possible to continue loading under more severe conditions than with fixed or multi-buoy type berths.

A number of different types of single point mooring systems have been developed, each with its own distinctive features. For the Ekofisk location we have chosen to install the conventional type of low profile buoy anchored with chains to the sea bottom to allow considerable spring action. (See Figure 2) This type of system has been specificially developed for the more exposed locations and the operability of the system is predictable from a considerable background of industry experience and thousands of hours of model testing.

The tanker loading buoys we have installed are of two different sizes. Both are designed for 60,000 ton tankers but one is designed for loading in 16 foot significant waves while the other is designed for 20 foot significant waves. Both buoys are designed to ride out the 100 year maximum storm conditions without a tanker attached. They are installed in 235 feet of water, 165 miles from the nearest point on shore, both records. The buoys are in the range of 40' to 50' in diameter with 6 anchors and chains holding them to the sea bed. The sea bottom at Ekofisk is a fine silty sand, providing an excellent anchor holding ground. A submarine hose connects the underside of the buoy to the loading pipeline on the sea bottom. The buoys are located 1½ miles from the production platform. Communication is by VHF radio and all control of producing wells and loading is from the production platform. Since the tanker is serving as a storage tank, production can continue only when a tanker is able to remain at the buoy.

Our analysis of the available meteorological and oceanographic data played a large part in our decision to attempt this method of producing and loading. A conventional single point mooring system requires the assistance of relatively small mooring vessels to transfer the floating mooring lines and hoses to the tanker. The sea state in which these vessels can operate necessarily becomes one of the parameters for determining operating time. From previous operating experience we selected, as a starting point for our study, an 8 foot sea as the limiting sea for making the tie up to the buoy.

Once the tie up has been accomplished the tanker can ride at the buoy up to any conditions for which one chooses to design the system. As a practical matter an upper limit of operating sea state is reached at a point where the loading hoses hanging over the side of the tanker are endangered by wave action or the sea state and wind velocity make it unsafe for the loading crew to remain on deck. This point is probably reached somewhere in the range of 15 to 20 foot waves.

We found from oceanographers predictions that we could expect significant waves of 8 feet or less about 85% of the time and significant waves of 15 feet or less 97.5% of the time. (See figure 3).

Significant waves are defined as the average of the highest one third of the waves observed passing a stationary observation point in a 20 minute period. The highest waves are approximately 1.5 times the significant wave height.

The wave observations on our drilling rig, the Ocean Viking, are recorded by the rig engineer once each hour after observing the waves passing a graduated scale on one of the pontoons. The engineer records a range of wave heights, for example, 8 feet to 10 feet. The rig is a semi-submersible so the wave observations are affected somewhat by the heave of the rig. However, in the range of wave heights we are most concerned with, this heave is measured in inches and can be neglected. In all our analyses we have used the high end of the observed range, so that these data represent what might be termed as an average maximum wave height. If we multiply the significant waves of the oceanographers predictions by 1.5 to obtain a predicted maximum, we find very good correlation with the Ocean Viking data. (See Figure 4).

To be conservative in our predictions of operating time we chose to use the Ocean Viking data analysis which indicated waves of 8 feet or less 63% of the time and 15 feet or less 86% of the time, while waves of 20 feet or less occured 93% of the time.

This was an encouraging start but it did not give the whole picture. One cannot expect tankers to arrive for loading when the weather is just right for tying up. Other questions we had were: If a tanker started loading and then had to leave the mooring before finishing, how long would it have to wait on the average to return to the mooring to complete loading? Would it be worth waiting to return to the buoy and finish loading or should the tanker depart with a partial load? Would there be long periods of downtime in the winter months? How would downtime for maintenance on the buoy affect the useful loading time? Should more than one loading buoy be installed and if so, how many?

These questions were partly answered by programming the computer to tabulate the time involved when waves reached 20 feet, the point at which a tanker would have to leave the mooring, until the waves subsided back to 8 feet, the point at which a tanker could return to the mooring, and the number of occasions when this occured. The results are shown in Figure 5 which indicates that the average downtime would be slightly over 2 days. Obviously this analysis can be carried further to find whether these downtime periods occur in rapid succession during certain months as this could change the picture somewhat.

To investigate the feasibility further we constructed a computerized model of a loading program superimposed on the weather data using the following parameters:

1. Select the number and size of tankers needed to move the planned production to the expected markets. This determined average round trip times and frequency of arrivals at the loading buoy.

2. Specify the average time required to tie up, load and disconnect from the buoy. We assumed 2 hours each for tie up and disconnecting. The loading rate is equal to the production rate when there is no storage.

3. Specify the maximum wave conditions under which the tie up to the buoy can be made -- 8 feet in this case.

4. Specify the wave conditions under which the tanker must leave the buoy -- 20 feet in this case.

5. Select the number of buoys to be installed -- 2 in this case.

6. Assume a routine maintenance period for each buoy to be introduced at random by the computer program -- 2 weeks assumed.

7. Assume that if a tanker is loaded 75% or more when it is forced to leave the buoy by weather it will proceed to the discharge port rather than wait to tie up again to complete loading.

Obviously these parameters can be varied as desired, but using this particular set of conditions we found that we could expect to move over 80% of the planned production without any storage. This encouraged us to go ahead with offshore loading plans in the Ekofisk field to test our theory. A sample page from the computer study is shown in Figure 6. The study is summarized in Figure 7.

This transportation model can be carried a step further by introducing storage to allow production to continue when weather conditions prevent tanker loading. It is then possible to determine the amount of storage needed to optimize production. Looking back at Figure 5 one can see that 10 days of storage would be about enough to eliminate all downtime.

Together with the study of weather data and the application of existing techniques to offshore loading we have introduced several other ideas to improve loading performance.

First we have installed wave recorders, current recorders and wind speed recorders to assist the operating staff in evaluating site weather conditions more accurately and to collect additional data for future design.

We have designed our buoys with a single underwater hose and a single surface hose to minimize maintenance problems. To further minimize floating hose problems we have reduced the hose length and size to a minimum and fitted the tankers for bow loading. A special A-frame and clamp has been fitted on the forecastle for hanging the hose vertically and deck piping has been extended to this point. (See Figure 8).

We are also using a single mooring line to minimize entanglement problems. To enable the tankers to moor with a single line we have fitted them with a special bow chock so that the line can be taken aboard over the forepeak on the center line of the tanker.

We are also experimenting with a constant tension winch mounted on the tanker bow to cushion the repeated shock loads on the mooring system. Also the tankers are specially ballasted and are equipped with steam turbines so that we can experiment with reducing mooring loads by maintaining a few turns on the screws.

As mentioned previously the tie up to the conventional single buoy mooring is limited by the operating capabilities of the mooring launch. If the tanker could tie up in more severe conditions that 8 foot waves the downtime could be greatly reduced. We have installed trailing lines tying the mooring line and hose together and are experimenting with having the tanker crew grapple for these lines and tie up unassisted.

Our operating experience has been limited to less than 2 months to date, but we have already experienced gales with winds to 60 knots and seas to 33 feet. The tankers were able to remain at the buoys and continue loading with winds in the 40 knot range and seas to 20 feet maximum.

The biggest unknown at present is the service life of the loading buoys in the Ekofisk environment. Routine maintenance can be programmed, but we recognize that if the underwater hose or chains break during the winter months, a buoy could be out of service for a lengthy period. We feel that preventive maintenance will minimize this problem and that the use of 2 or possibly more loading buoys will reduce the risk of losing all loading facilities at the same time. We will have to accummulate much more operating experience to answer many of our questions, particularly whether this method of loading is practical on a long term basis.

Meanwhile, we are continuing to study other types of mooring systems for possible future application in this and other hostile environments.

DISTRIBUTION OF WAVE AND WIND DIRECTIONS

ANNUAL BASIS

EKOFISK AREA-NORTH SEA

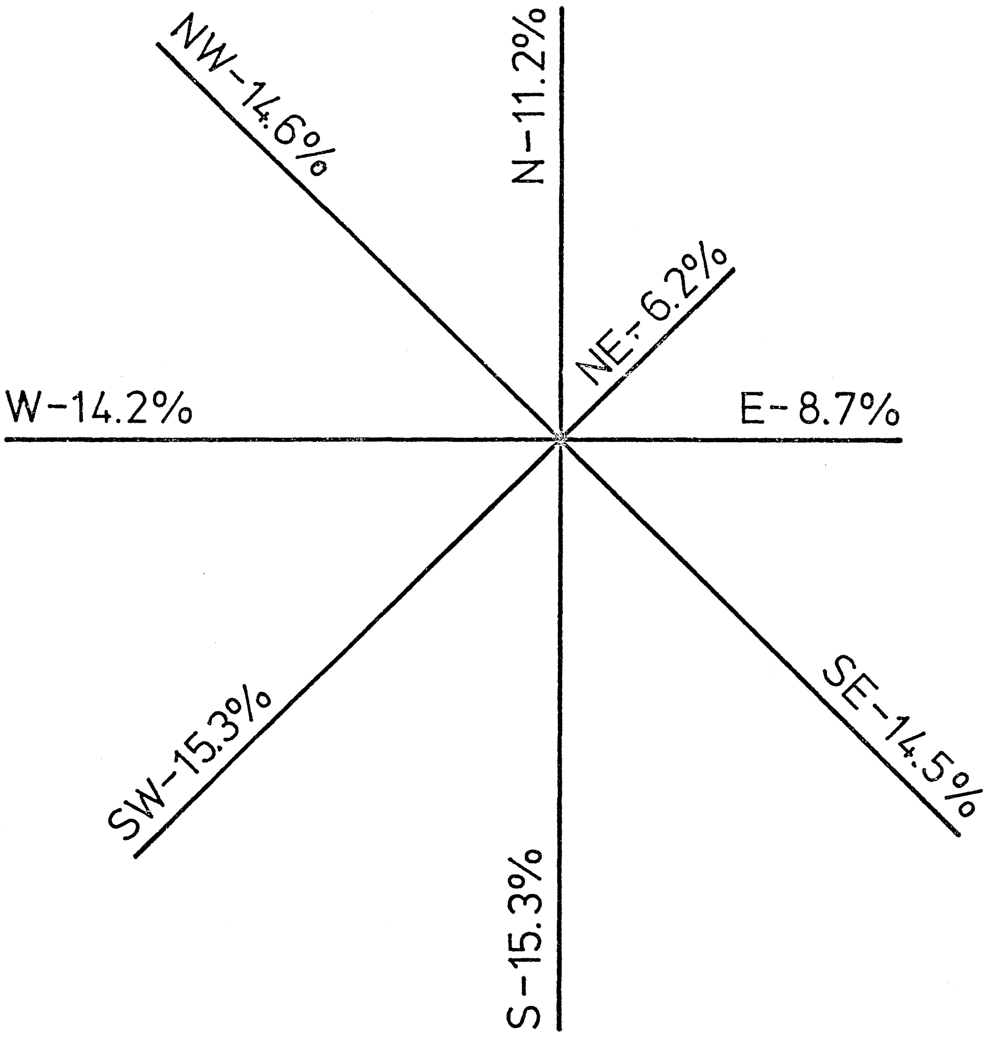
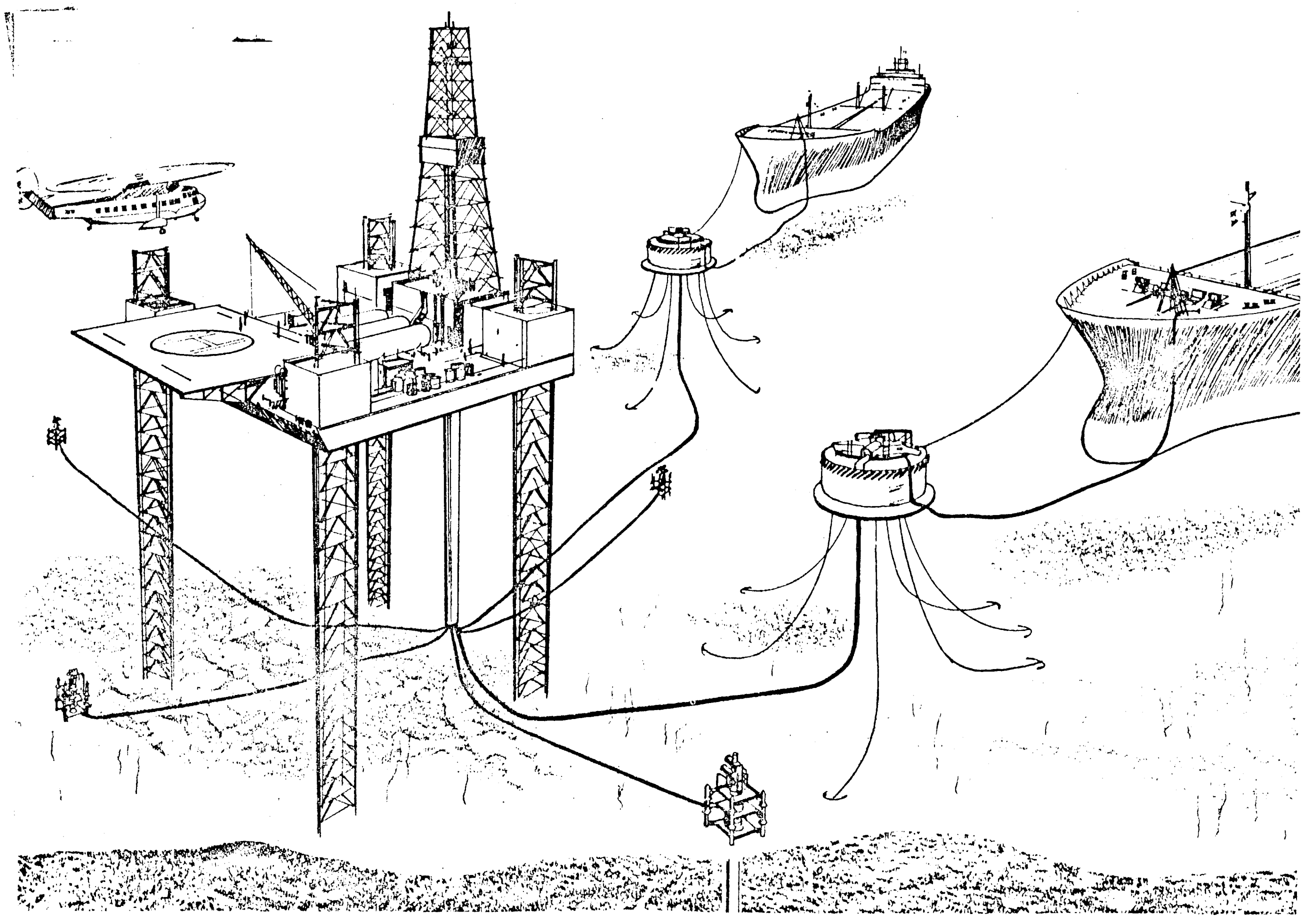


Figure No. 1



EKOFISK PRODUCTION & LOADING FACILITIES
Figure No. 2

DISTRIBUTION OF SIGNIFICANT WAVE HEIGHTS

ANNUAL BASIS
EKOFISK AREA-NORTH SEA
(LONG TERM AVERAGES)

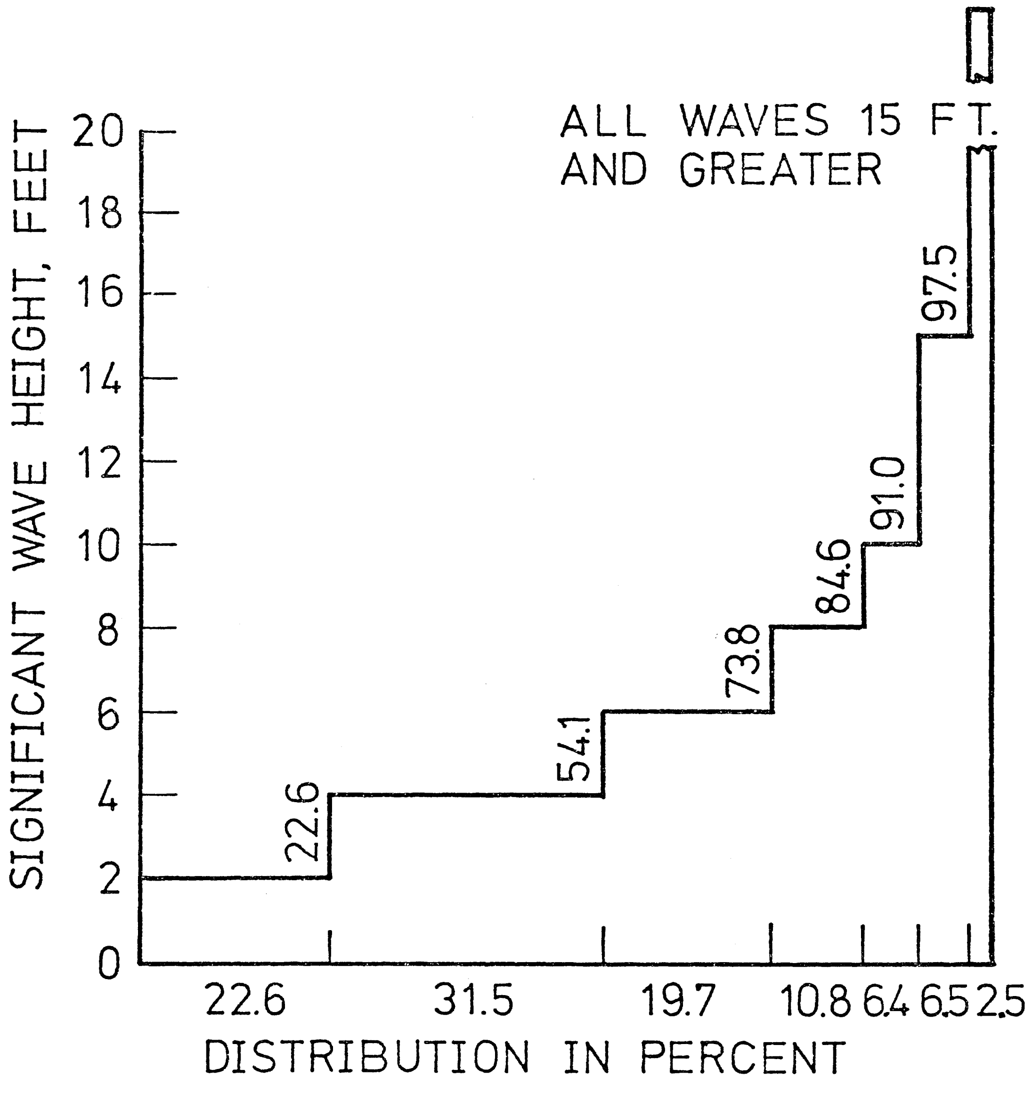


Figure No. 3

DISTRIBUTION OF AVERAGE MAXIMUM WAVE HEIGHTS

4 YEARS HOURLY OBSERVATIONS EKOFISK AREA-NORTH SEA

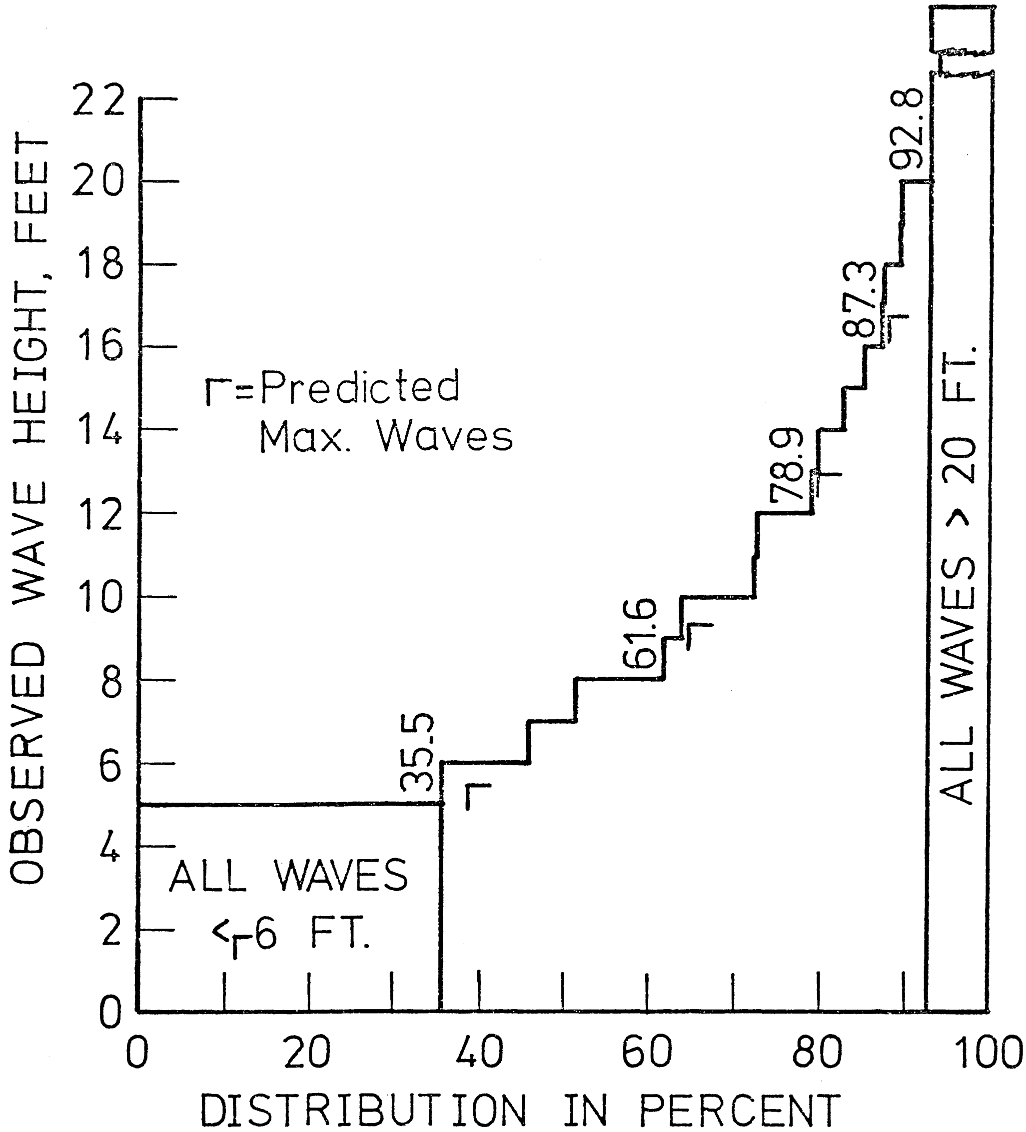


Figure No. 4

LOADING DOWNTIME DUE TO HIGH WAVES

EKOFISK AREA-NORTH SEA

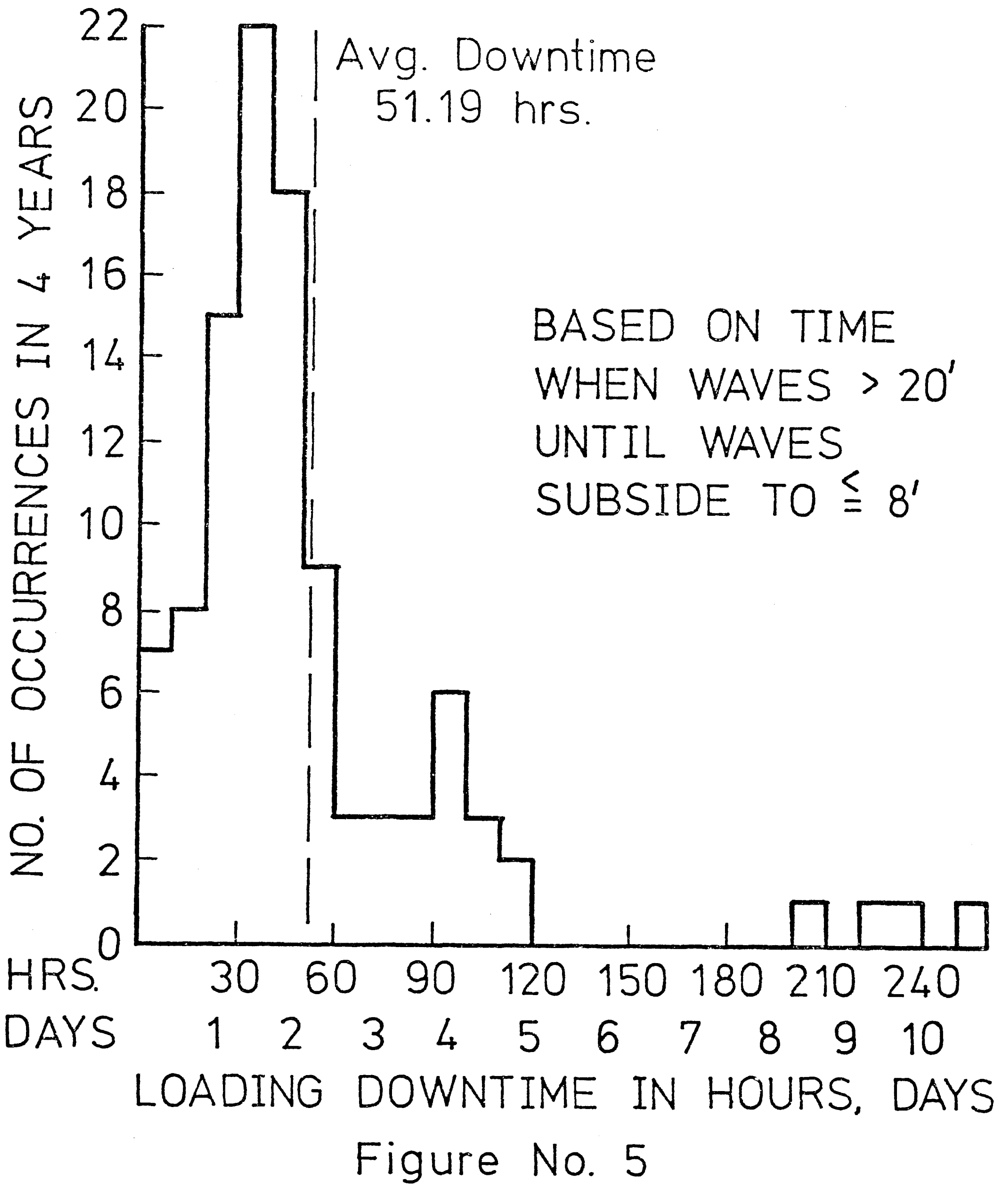


Figure No. 5

TYPICAL PAGE FROM TANKER LOADING STUDY

EKOFISK FIELD

DATE	HOUR	STORAGE	WAVE HT.	TANKER LOAD	ACTIVITY	BUOY NO.	TANKER NO.	CLOCK HRS.
1/27/70	800	0.	6.	0.	START MOORING	2	2	19598
1/27/70	1000	0.	6.	151664.	START UNMOORING	1	1	19600
1/27/70	1000	0.	6.	0.	START LOADING	2	2	19600
1/27/70	1100	0.	6.	151664.	UNMOORING COMPLETED	1	1	19601
1/31/70	300	0.	2.	0.	START MOORING	1	1	19689
1/31/70	500	0.	2.	0.	START LOADING	1	1	19691
1/31/70	500	0.	2.	151664.	START UNMOORING	2	2	19691
1/31/70	600	0.	2.	151664.	UNMOORING COMPLETED	2	2	19692
2/ 1/70	500	0.	21.	40000.	START UNMOORING	1	1	19715
2/ 1/70	600	0.	18.	40000.	UNMOORING COMPLETED	1	1	19716
2/ 4/70	1100	0.	8.	40000.	START MOORING	1	1	19793
2/ 4/70	1300	0.	8.	40000.	START LOADING	1	1	19795
2/ 7/70	800	0.	18.	151664.	START UNMOORING	1	1	19862
2/ 7/70	900	0.	18.	151664.	UNMOORING COMPLETED	1	1	19863
2/ 9/70	1500	0.	8.	0.	START MOORING	1	2	19916
2/ 9/70	1700	0.	7.	0.	START LOADING	1	2	19918
2/13/70	1000	0.	2.	0.	START MOORING	2	1	20007
2/13/70	1200	0.	4.	0.	START LOADING	2	1	20009
2/13/70	1200	0.	4.	151664.	START UNMOORING	1	2	20009
2/13/70	1300	0.	4.	151664.	UNMOORING COMPLETED	1	2	20010
2/17/70	500	0.	7.	0.	START MOORING	1	2	20098
2/17/70	700	0.	7.	151664.	START UNMOORING	2	1	20100

Figure No. 6

SUMMARY OF TYPICAL TANKER LOADING STUDY

EKOFISK FIELD

TOTAL HRS	20375
PRODUCTION BBL/DAY	40000
STORAGE	0
LOST PRODUCTION HRS	3756 (18%)
TOTAL BARRELS LOST	6259996
NO. LOADS BUOY 1	108
NO. LOADS BUOY 2	74
NO. LOADS TANKER 1	92
NO. LOADS TANKER 2	90

Figure No. 7

FIGURE NO 8 - TANKER LOADING AT EKOFISK SINGLE BUOY MOORING INSTALLATION