FINAL REPORT

Contract No. E-225-69(N)

The Development of Forecast Techniques for Wave and Surf Conditions Over the Bars in the Columbia River Mouth and at the Entrance to Yaquina Bay

by

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ABSTRACT

This investigation has been carried out primarily to define the Columbia River bar crossing problem, to determine the physical factors involved in hazardous transit developments, and to develop a method for predicting hazardous bar transit conditions sufficiently in advance to allow proper safety precautions to be effected.

Actual records of periods of bar closure for the years 1963 - 1969, as determined by the Columbia River Bar Pilots Association, provide a firm foundation for the entry into this study. Meteorological and oceanographic conditions leading to the closures, as well as those occurring during periods of closure, are being analyzed to identify the more immediate causes for such situations and also to determine the nature of their temporal and spatial evolution. Much of the background material necessary for this study has been compiled, and case histories on conditions leading to closure circumstances are being prepared to determine the various types of situation development.

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INTRODUCTION

The mouth of the Columbia River is one of the most formidable harbor entrances in the world during periods of heavy sea and swell. This is particularly true during the ebb tide. Over the bar, that relatively shoal area in the vicinity of the river entrance, conditions become very turbulent and hazardous at such times. Here the long period swell peak up as the water shallows and are often caused to break by the ebb tide. Every year lives are lost as a result of inexperienced boat operators attempting to cross this hazardous zone during adverse sea and weather conditions. Even on a relatively calm day, the ebb tide may create a bar condition which is too rough for small craft transit. Two of the most hazardous areas near the river entrance (see Figure 1), that part of Clatsop Spit between the south jetty and the bar channel and Peacock Spit (to the north and northwest of the north jetty), were aptly called the "Pacific Graveyard" (Gibbs, 1950), due to the large number of ships and men lost on and along them.

Gibbs' book would appear to overdramatize the losses of large ships, with currently available facilities, since experienced seamen follow the advice of the Coast Guard and seek the aid of the Columbia River Bar Pilots when conditions are hazardous. The Coast Guard's Columbia River lightship, located about 9 nautical miles west of Clatsop Spit, acts somewhat like a floating lighthouse for mariners approaching the mouth of the Columbia River. When wave conditions are unusually severe and persistent, ships may slow down and wait for a period of days near the Lightship until conditions subside to the point where the Columbia River Bar Pilots can come out and take them across the treacherous bar area.

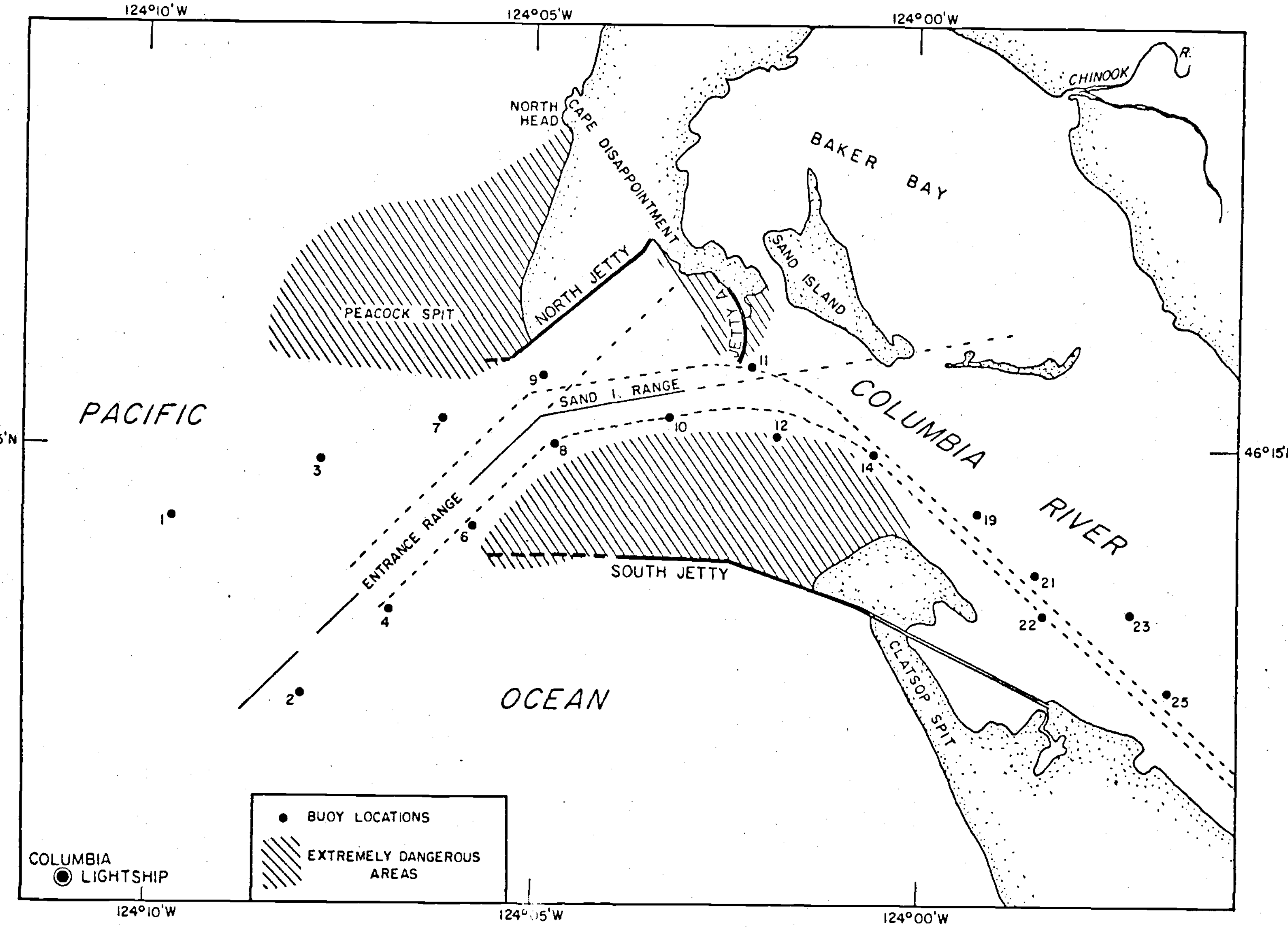

Figure 1. Map showing principal features in vicinity of Columbia River entrance.

Most boating disasters and the resulting losses in life involve small fishing boats and pleasure craft, which inexperienced operators allow to stray from the deeper channel waters into the more hazardous shoal areas to either side where they can lose control and broach. Every year several hundred requests for assistance by small boats in distress are handled by the Coast Guard's Columbia River Bar Patrol from Cape Disappointment. Even during the generally good weather months of July and August, this Bar Patrol is extremely busy since small boats are particularly numerous. For instance, in August 1969 over 300 cases of assistance were handled by just this one Coast Guard unit.

In view of the frequently hazardous nature of Columbia River bar crossing, the large loss in lives and vessels in the vicinity of the Columbia River mouth, and the great importance of the Columbia River entrance to both commercial and recreational activities in the northwestern U.S., ESSA decided that improved safety measures were essential. In June 1969, ESSA Contract E-222-69(N) was established with the Department of Oceanography at Oregon State University (OSU) to study the nature of the bar transit problem, to define the physical factors involved in hazardous transit developments, and to determine the actual role these factors play in such developments. Some of the factors which it was expected would be of particular concern in such cases were the associated synoptic meteorological pattern, its more significant wave generation areas as well as their intensity, speed and direction of movement; resulting sea and swell characteristics in the vicinity of the river mouth; tide stage and tidal currents; local weather effects (e.g., presence or absence of storm tides, visibility limitations due to precipation, fog or sea spray); river runoff; and bottom topography. The ultimate objective of the contract study was to develop a method to predict the onset, duration and time of cessation of hazardous bar transit conditions. The principal goal of the effort was to prevent the loss of ships, cargoes and lives by having the capability to issue advisories of impending hazardous bar transit conditions sufficiently in advance to allow proper precautionary measures to be taken by boat operators prior to committing themselves to a transit of this potentially treacherous zone. Even the highly experienced ship operators could profit considerably if they had the capability to plan their operations more efficiently and safely. By taking advantage of the additional lead time provided by a reliable advisory issued sufficiently in advance of impending hazardous conditions, they could avoid the more risky, "spur of the moment" decisions, which at the time must frequently depend on existing sea and weather conditions. If the less experienced small boat operators could be properly educated as to the hazards which might be encountered in the vicinity of the Columbia River mouth and could be expeditiously advised on expected hazardous bar transit conditions prior to embarkation or reaching a point of no return in transit commitment, it should be possible to save several boats and lives each year.

The Columbia River Bar Area

The bar at the mouth of the Columbia results not only from the release of sediment loads carried by the Columbia River but also sediments transported and shifted by littoral currents and tidal currents. The interactions between tides, river discharge, waves, tidal currents, littoral currents, sediment, jetties, and dredging operations cause a continual change in submarine and peripheral land features and thereby prevent detailed description. Over the past several years there has been a continual need for jetty rehabilitation and dredging along the river and harbor entrance channel in order to protect the channel and maintain suitable channel depths in the face of the many powerful forces of change. The large tidal range in this region is particularly problematic. The range from mean lower low water to mean higher high water is about 8.5 ft; however, the extreme tide range (considering spring tides and possible storm tides) may exceed 14 ft. The ebb tide currents are quite strong, reaching 5 to 8 knots in certain areas. They frequently reach 8 knots where the seaward flowing water is deflected by Jetty A (see Figure 1), according to the booklet, "Columbia River Bar Information," by the Coast Guard. When a large meteorological tide coincides with a high astronomical tide and large river discharge, heavy surf and resulting currents are allowed to act far beyond normal water boundaries over ordinarily shallow water and adjacent lowland areas and to cause further modifications.

Bar Closure

The Columbia River Bar Pilots use operational terminology when recommending bar closure. They consider the bar conditions to be too hazardous when the risk involved in crossing becomes no longer acceptable. Although several meteorological and oceanic factors could be involved, it is the total effect that determines safety of transit over the bar area. However, our investigation has noted that most of the bar closures were during periods of ebb tide and often extended a few hours beyond when hours of darkness were involved. It is for this reason that we selected a cutoff of 9.5 hours closure duration in our study of closures over the period 1963-1969. This allowed us to focus our attention on those closures caused primarily by the large waves created by offshore storms, rather than those conditions brought to a head by the ebb tide. Ebb tides can be predicted reliably well in advance and thus can be taken into account in departure and arrival plans. It is the more severe sea condition which transcends the tidal contribution period for which we now wish to develop the capability of prediction.

Observing Problem

Observation of the overall manifestiation of sea and weather conditions in the vicinity of the Columbia River mouth, when hazardous situations arise, becomes quite problematic for the surface based observer since the area to be viewed is so vast, as only a person who has witnessed this region can fully realize. Some aspects of this problem are:

(1) The rough road which extends out to that part of the South Jetty near the lookout tower may be covered with water during periods of high tide and storm conditions.

(2) This rough-surfaced jetty extends seaward about three and a half miles beyond the road endpoint. During periods of large offshore swell, the resulting breakers send large surges of water and spray over the outer couple of miles of South Jetty.

(3) The river mouth is 2 to 3 miles wide in this entrance area.

(4) Often visibility is severely reduced over the whole area during storms due to precipitation and sea spray.

(5) Even from a helicopter, if one descends to a level where essential details can be identified, the view of the area as a whole must be sacrificed due to its vastness.

(6) The unusually large breakers break too far seaward along the jetty for accurate measurement of dimensions. This is particularly so when the visibility is greatly reduced by precipitation and sea spray. (Under such conditions it is extremely hazardous to venture very far seaward along the jetty.)

(7) Although the long-period swell (9 to 16 seconds) usually cause the most severe wave or breaker developments over the shallow bar areas,

since they contain the larger amounts of energy, they are often masked to the observer at sea by the more obvious sharp-crested, short-period wind waves which are superimposed through local generation on the sea surface. Thus, this high-energy, long-period swell may arrive unannounced at the river entrance.

Helicopter photographs have allowed us to effectively investigate the pattern of waves and breakers established during periods of large waves and heavy surf over the bar and lower part of the river mouth in general. They have helped us to determine those areas over this region which are most hazardous to ship operations and to associate them with the underlying submarine topography.

Buoy Operations

Dr. Neshyba and his group, aided by the crew of the U.S. Coast Guard Cutter MAGNOLIA placed the TOTEM I buoy on station in September 1969, using a 2-point mooring system developed at O.S.U. It was moored in waters 550 meters deep at 45°02.6'N, 124°44'W (about 30 miles west of Cascade Head, between Lincoln City and Neskowin, Oregon). Later the buoy was instrumented with an interim meteorological station and a wave sensor array for measuring deep water wave characteristics. TOTEM I with its unique mooring system successfully withstood the severe winter weather and sea conditions of the northeast Pacific. Weather data (temperature, pressure and winds) were routinely transmitted from this buoy to our land-based receiver and they were in turn relayed on to the National Weather Service for further dissemination. A recorder was connected to the wave sensing system on TOTEM I but the tapes received were not readable.

In October 1970, TOTEM I was to be removed from its mooring and TOTEM II installed as its replacement. During the exchange an unforeseen load was placed on TOTEM II and it sunk. However, TOTEM I was saved and brought back to shore for maintenance after its 14 months at sea.

General Aspects of Project

There is no point in rehashing the available literature on waves, surf and their prediction, since this has been done innumerable times and serves no useful purpose here; however, U.S. Army Coastal Engineering Research Center (1966) and N. A. Pore (1970) are recommended for their excellent bibliographies on these subjects. Likewise, there is no point in including a discussion of wave equations and the simplifications used in deep and shallow water since these too have been very well worked over in standard texts and a large number of the publications included in the referenced bibliographies. Terminology has likewise been well accounted for in the above referenced publications and the Glossary of Oceanographic terms (U.S. Naval Oceanographic Office, 1966).

A couple of the more widely accepted approaches to sea and swell forecasting are the Sverdrup-Munk-Bretschneider technique and the Pierson-Neumann-James method, both of which are discussed in U.S. Army Coastal Engineering Research Center (1966). U.S. Naval Oceanographic Office (1955) gives a more comprehensive discussion of the Pierson-Neumann-James method. For a discussion of breaker and surf forecasting, U.S. Navy Hydrographic Office (1944) is recommended. For brief discussions of the above methods and their applications, the following references are recommended: Griswold (1964), Pore (1970) and Shields and Burdwell (1970).

Here we are primarily concerned with the evolution of meteorological patterns that lead to wave developments that result in hazardous Columbia River bar crossing conditions. Our goal is to extend the length of the prediction period in time so that advisories to marine activities can be issued sufficiently in advance for proper safety precautions to be taken or appropriate operational decisions to be made. If the marine forecaster is alerted as far in advance as practicable to the possibility that such a development may be taking place, he can monitor its progress with time so as to increase the reliability and accuracy of predictions.

In the area of wave formation (generation area) the highest waves present at a particular time will depend on the wind velocity, fetch, duration and those waves already present when this particular wind field was established. Since a relatively stationary storm would have a fetch limited by the size of the storm, and a rapidly moving storm would limit its generation capability by outrunning the waves generated along its path of movement, it appears that a storm moving with a velocity such that its fetch would be extended to the point of maximum wave development for the effective wind velocity could lead to the most hazardous situations. Such a fetch, moving at the group velocity of waves in that part of the wave spectrum which causes the more hazardous Columbia River bar situations, might lead to particularly violent bar conditions.

The height of the swell decreases and the period of maximum energy increases as it travels through a decay area (area of little or no wind) due to selective attenuation (by which shorter period waves die out as the longer period wave portion of the spectrum persists). As the waves progress toward shore, they begin to feel bottom when the water depth decreases to one-half wavelength, and then as the water becomes more shallow certain changes in wave characteristics take place. In general, as the water becomes increasingly shallow, wave speed decreases, the wavelength becomes shorter and the waves increase in height. By definition, wave velocity equals the wavelength divided by the period, $C = L/T$. Since there is no apparent loss of crests as the waves move shoreward, the period must remain constant and, therefore, the ratio C/L remains constant. Waves generally break at a depth of 1.3 times their height.

Due to the much greater length of swell (as compared to wind-waves) it is much more affected by bottom restriction transformations (shoaling and refraction affects). Submarine ridges become zones of convergence (increased wave and breaker height), whereas, submarine channels become zones of wave divergence (decreased wave height). Offshore winds, ebb tides and opposing currents issuing from river mouths cause waves to break sooner, whereas onshore winds and rising tides cause waves to break further shoreward.. (In an area, such as the vicinity of the Columbia River mouth, where the tidal range is large, the variation in depth with tidal stage plays a large part in determining when and where the long-period swell will break.) As a result of the shoaling and refraction effects, the long-period swell may rise well above its deep-water height when breaking over the shoal areas. The short-period, relatively steep wind waves are much less affected by shoaling processes and often break at their deep water heights or less in shallow water. By remaining in the deeper entrance channel through the Columbia River bar area, hazards can be minimized. Wave heights are somewhat diminished and breaking is often prevented as a result of the divergent effect (on the waves) of the deeper waters in the channel; also, some of the most hazardous tidal current zones are avoided by remaining there. However, the shoaler areas of Peacock Spit and Clatsop Spit have a convergent effect on the waves causing them to break and present hazardous, turbulent conditions when seas are large. The Clatsop Spit flank of the channel is particularly dangerous during ebb tides when breakers may extend for a considerable distance along it on the south side of the entrance channel. When there are seas or swell of any significant size the breaker and surf conditions are very hazardous along Peacock Spit regardless of the tidal stage.

In addition to determining the evolution of the meteorological patterns that lead up to the hazardous wave developments, we are interested in determining which of the sea and swell forecasting approaches appears to be most applicable in prediction of the hazardous bar conditions. We are also interested in making this prediction scheme compatible with the use of National Meteorological Center (NMC) prognostic products.

Example of Storm Causing Bar Closure

Mr. G. B. Burdwell provided the following descriptive material concerning a very intense storm which affected the northeast Pacific and Pacific coastal region of the U.S. and Canada over the period 3-6 November 1969. The storm was particularly notable because of the unusually high waves generated, with some ships indicating heights near 50 feet. AT 1800z on 3 November the storm's center with a pressure of 988 millibars (mb), was located near 44°N, 146°W. The low was moving northeastward at about 28 knots and beginning to deepen rapidly. At 0600z on 4 November, a Japanese ship reported northeast winds of 60 knots and a pressure of 965.3 mb at 48.7°N, 140.5°W. Up to this time the storm had been moving rapidly to the northeast. However, it then decelerated to less than 15 knots and turned eastward, setting up a moving fetch aimed at the Oregon coast. Winds within this fetch were 50 knots or more for at least the next 30 hours, and the effective length of the fetch eventually became more than 500 nautical miles, since the wind field travelled along with the major wave train that it generated. At 1800z on the 4th (see Figure 2), the lowest pressure had dropped to 944 mb. Winds of 50 knots or more were reported from all quadrants of the storm at this time; and, in the southwest quadrant,winds of 48 to 56 knots were being observed within a 400 mile radius of the center. Heavy rain and strong winds were also occurring along the coasts of Washington and Oregon as the related front pushed inland between 1700z and 1900z on the 4th.

During the next 24 hours, the low center moved eastward and slightly south as it slowly filled. Winds in the south and southwest quadrants remained generally 50 knots or more, and continued to build the waves that

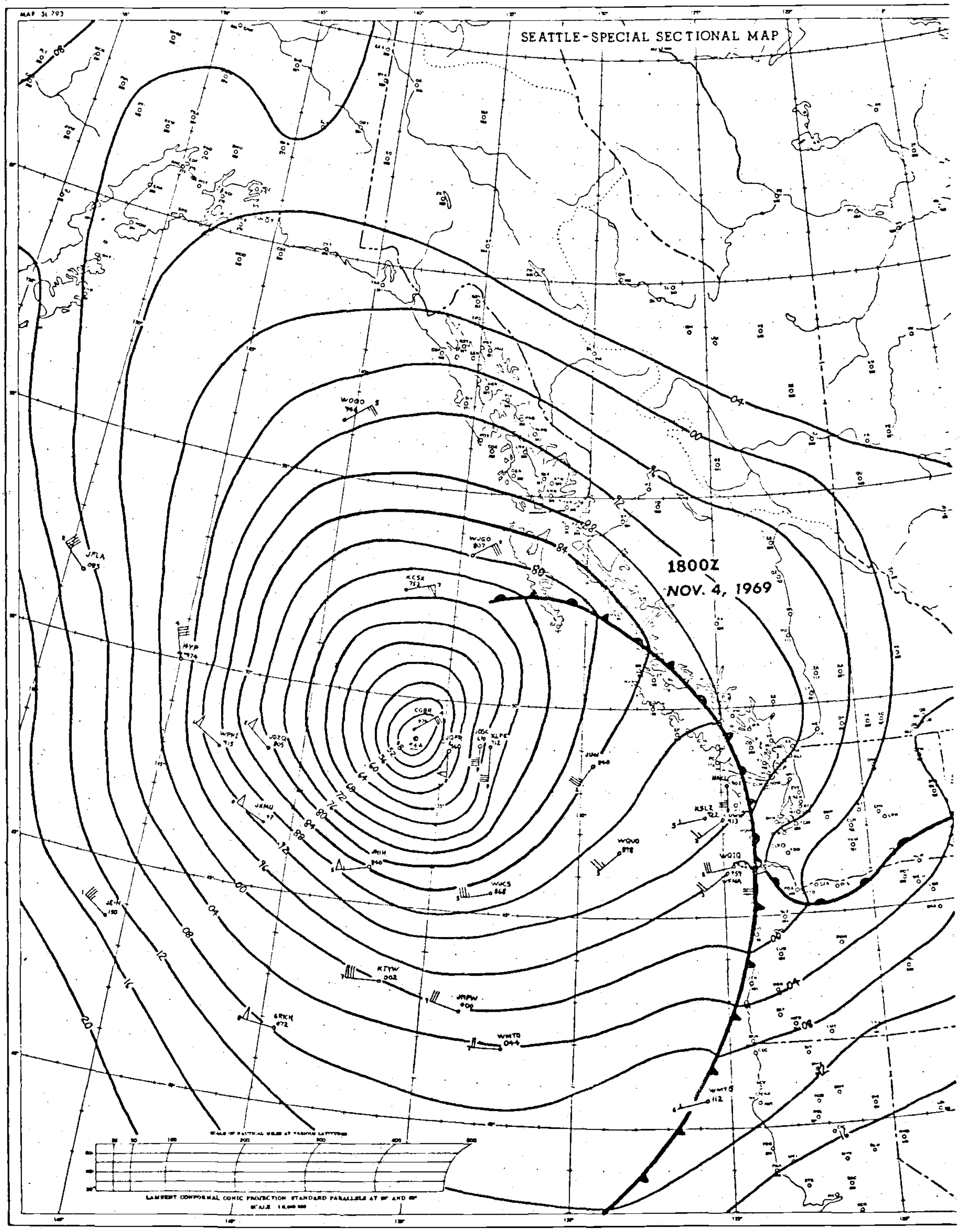

Figure 2. Surface analysis for 1800z on 4 November 1969.

affected the Oregon coast. By 1800z on the 5th, the low center had moved to 47.5°N, 129°W and filled to 972 mb. Some ships to the south and southwest of the storm center still reported winds of 50 to 55 knots and seas and swells ranging from 30 to 50 feet or more. The storm turned northeastward by 0000z on the 6th and filled rapidly as it entered the Strait of Juan de Fuca.

Mr. N. Kujala observed conditions in the vicinity of the Columbia River bar during this period and communicated with the Bar Pilots and Coast Guard to obtain their observations and actions. At 1800z on November 5 (just after high tide) the bar was closed to ships requiring pilots. The Pilots Association felt that conditions were too hazardous to transfer pilots at sea. However, one ship departed without a pilot at about 1900z on the 5th. At that time, wind speeds were 45 to 50 knots and breakers were estimated up to 30 feet in height in areas adjacent to the channel. Photographs taken by Mr. Kujala during this period showed the deeper waters of the channel as a dark blue color flanked on either side by white breakers along the shoaling sides of this channel through the bar. Waves, in general were observed to be coming from the west southwest with periods of 11 to 14 seconds. Near the end of the South Jetty and Clatsop Spit large breakers from the west southwest were estimated to be 30 to 40 feet in height, whereas, in the more protected deep channel between the jetties, heights were generally 15 to 20 feet, as reported by the Columbia River Bar Pilots and the U.S. Coast Guard. Photographs show the breakers flanking the jetty to send large surges of water and spray over the jetty. Since the huge waves break out near the end of the jetty where depths are in the 40 to 50 ft. range, the reduced visibility in spray greatly limits the observer's ability to estimate wave characteristics under such conditions from either the top of the jetty or the South Jetty tower. The Columbia River Lightship, which is located about 9 miles west of Clatsop Spit, and which is ordinarily very conservative in its wave-height reports, reported waves 25 feet high on both the 4th and 5th of November. The bar was considered closed to ship traffic until 1430z on 6 November, for a total of 20.5 hours.

Mr. Burdwell has noted that there are usually 5 or more storms each year which produce coastal winds of comparable or greater intensity. However, the exceptional developments caused by this storm were associated with the size, intensity, track and speed of the moving fetch.

Attack on the Problem

It was decided that bar closure periods, as established by the Columbia River Bar Pilots Association, could satisfactorily represent those conditions which we wanted to investigate and for which we desired to provide a prediction scheme. It also appeared that an excellent approach to this research would be to study the offshore wave characteristics associated with hazardous bar conditions and to trace the development of those storms (back through space and time) which caused such conditions. By determining how such situations evolved and identifying the meteorological patterns as they appeared during various stages of development, it was believed that prediction periods could be significantly extended. Of course, the local weather, river stage, currents, tidal stage and other contributions to the bar crossing situation also had to be taken into account in this study.

Bar closure data for the period 1963-1969, provided through the courtesy of the Columbia River Bar Pilots Association, was selected as the basis for the investigation. The study was limited to those cases where the bar closure was in excess of 9.5 hours. By so limiting bar closure duration, those cases where the lower energy waves become hazardous only over short periods of time, due to amplification by ebb-tide effects, could be effectively filtered out. (The tide stage is routinely predictable, and here we wished to attack those situations which exceeded this effect.) In this way we could focus our attention on those cases where the waves themselves and the weather conditions that generated them were the primary factors. This left about 78 bar closure periods to investigate, some of which exceeded 2 days in extent. The following are some of the key items used in support of this study:

(1) Ship reports over the area surrounding and seaward of the Columbia River mouth for the period leading up to bar closures and continuing through each bar closure period. These data are being used to obtain an understanding of the deep water wave and weather characteristics which are associated with bar closures.

(2) Microfilm of Northern Hemisphere Weather Analyses, to include surface through 500 mb levels for the period leading up to bar closures through the bar closure periods. These charts provide such data as storm locations, their direction and speed of movement, their central pressures and whether they are deepening or filling, characteristics of the fetch and fetch winds, general nature of the meteorological pattern and its change with time, development and movement of surface features in relation to upper level patterns and flow.

(3) Ship "P" data for the periods of concern. Since Ship "P" is in a fixed location (50°N, 145°W) and can provide good, reliable data, it was felt that during particular types of development certain relationships may be reflected in the data available at this site such that we may be able to use information from this fixed point for control purposes in prediction decisions.

It is anticipated that the nature of the fetch as well as its direction and speed of movement play a key role in determining the wave generating potential of those meteorological systems to be investigated. However, other meteorological features and local factors will be given due consideration in this investigation.

Much of Mr. Enfield's effort, up to the present, has to a great extent been involved in the time consuming process of reproducing pertinent parts of applicable meteorological analyses in order to have them available for his case history studies. (The microfilm analyses are only available for limited periods of time through interlibrary loan.) Table 1 shows the current status of the data procurement aspect. In addition to the items listed in Table 1, other items are to be considered, such as the U.S. Coast Guard Cape Disappointment unit's observations of Columbia River mouth conditions, Columbia River stage data, possibly lower level wind and stability correlations for the Ship "P" site, etc. in relation to bar closure developments.

Mr. Enfield is now actively engaged in identification of the swell and associated meteorological developments responsible for each bar closure period; plotting storm tracks; studying pressure center developments (deepening and filling); investigating associated fetch characteristics; identification of what appear to be marginal closure situations from the offshore meteorological and oceanic indications, and further examining them to see

TABLE 1. Status of Data Procurement

scription of data	Principal Uses of Data	Percent obtained & data source
and duration of those bar ures in excess of 9.5 hours 3-1969)	Determine the conditions that caused these significant bar closure periods.	100% CRBPA[1]
-hourly surface synoptic iyses for the N. Pacific for period 72 hours prior to during closure.	Identify meteorological features associated with significant offshore swell reported by ships; show pattern development with time; study wave generation features (fetch size, winds, movement, etc.); obtain suitable statistical data; etc.	90% NOAA[2]
hourly 500 mb analyses for Pacific for 72 hours prior and during closure.	Relation of upper level pattern and flow to surface pattern evolution during the periods of pertinent wave development.	25% NOAA
-hourly swell reports for sden Square #157 prior to during closures.	Determine direction, period and height of the ocean swell associated with each bar closure period.	100% NOAA
ee-hourly surface weather ervations from Ship "P" for closure months.	Possible use of this reliable point source data in correlation with situation developments; also, possible input to prediction decisions.	100% NOAA
thly summaries of observed h and low water levels at gue Point (Columbia River).	Determine actual water level contribution to those bar closure situations which are under study.	100% NOAA

RBPA - Columbia River Bar Pilots Association.

OAA - National Oceanic and Atmospheric Administration.

if there is either a significant local contributing factor or a much more distant source (e.g., tropical cyclone of hurricane or typhoon intensity, large distant extratropical cyclone). Case histories will be prepared for those situations which are typical of modal development patterns to further identify the inputs to bar closure situations. These steps will in turn contribute to the development of the prediction scheme.

With regard to bar closures for the period 1963-1969, an average of 9.7 days (with closures in excess of 9.5 hours) occurred per year with a maximum of 14 in 1964 and a minimum of 8 in 1968. Over the 7-year period, 52% of these closure days fell in December and January, and 97% occurred from October through March. A plot of closures versus hours of the day indicates a clear bias toward night closures. This is logical in view of the increased navigational difficulty and uncertainty with regard to conditions during hours of darkness. A plot of closures versus hours of the tidal day shows a greater incidence at the onset of lower low water and a secondary increase at the onset of higher low water, although closure periods in excess of 9.5 hours were chosen to avoid those cases where ebb tide exerted primary control. Therefore, although the selected duration limit guarantees that tides were not the only factor involved, there is a tendency to keep the bar open until the onset of ebb tide.

Recommendations

In addition to the more formalized approach of this project to provide a prediction scheme, it appears that the following additional actions might be taken to increase the effectiveness of marine safety and wave prediction programs:

(1) Publish occasional popular articles on the nature of coastal sea and weather hazards. The small boat operator more readily accepts and understands warnings concerning the hazardous nature of coastal waters when the accompanying local weather conditions are similarly adverse. However, it is more difficult for him to comprehend the hazardous bar conditions caused by swell from distant wave generation areas during locally favorable weather conditions.

(2) Obtain more complete data on waves at sea through recording systems installed on ships and buoys. Observations of existing waves at sea serve as input to forecast computations of sea, swell and surf and also to verify forecasts of same. In visual measurements of waves at sea, the large, long-period swell (9 to 16 seconds), which usually cause the most severe wave or breaker developments over the shallow bar areas, are often masked to the observer at sea by the more obvious sharp crested, short-period wind waves superimposed through local generation processes, and thus these long high-energy waves may arrive unexpectedly in the coastal region.

(3) Work out a program with the U.S. Coast Guard to obtain improved sea and swell observations from their lightships at sea and improved breaker and surf observations from Coast Guard observers on duty in lighthouses and towers along the coast. Installation of sensors and recording systems at

key locations would effectively improve our understanding of wave forces and their variability. Most of the wave data now used as design criteria for nearshore construction of jetties, breakwaters, groins, piers, etc. along the northwestern U.S. coast are based on wave hindcasting techniques. Therefore, they are based on waves that may never have occurred.

(4) Include 3 or 6 hourly breaker and surf observations in the daytime reports of those cooperative observers located at coastal sites in order to improve our understanding of coastal conditions and their variability.

Conclusions

We have been able to determine the nature and magnitude of the Columbia River bar transit problem during adverse sea and weather conditions through a study of available sea and weather records, discussions with members of the Columbia River Bar Pilots Association and the U.S. Coast Guard, and through actual observations and photographs of the conditions involved.

We have obtained a basic source of information, actual records of periods of bar closure (1963-1969) as determined by the Columbia River Bar Pilots Association, on which to base a rather comprehensive study of the hazardous bar crossing conditions, what causes them and how such situations evolve from a meteorological and oceanographical standpoint.

Much of the background material necessary for this study (i.e., applicable portions of pertinent surface and upper level analyses, ship reports of the applicable sea and swell conditions, tidal stages for the bar region, etc.) has been compiled. Analyses of the individual situations are being performed. Case histories are being prepared for particular modes of development. The goal of the planned continuing work is a prediction scheme which will apply to the various modes of development.

Acknowledgments

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Appreciation is expressed to the members of the Columbia River Bar Pilots Association for providing data on bar closure periods of the past (1963-1970), which have provided a firm basis for this study, and for observations taken by the Bar Pilots from their Flag Ship during particular storm situations.

Appreciation is also expressed to the Commander of the Thirteenth Coast Guard District and members of his staff who have supported this study, and to the Commanding Officer of Coast Guard Group Astoria along with members of his Group. The access to the Coast Guard Tower on the South Jetty of the Columbia River entrance and excellent aerial photographs obtained by Coast Guard photographers from Astoria Air.Station helicopters have been great assets to this study.

Support by the U.S. Army Corps of Engineers has been likewise appreciated. In early 1970 the Coast Guard returned the South Jetty tower to the Army Corps of Engineers; and, Mr. G. Shelver, the local Army Engineer-in-Charge, provided assurance that we could continue to use the tower for observation of wave and surf conditions.

Gratitude is expressed to the following for their valuable support and participation in the program:

Mr. Gerald Burdwell (Marine Advisory Meteorologist, National Weather Service at the Marine Science Center, Newport, Oregon) - Mr. Burdwell investigated certain recent meteorological and oceanic situations which were associated with hazardous bar transit conditions.

Dr. Stephen Neshyba (Department of Oceanography, OSU) - Dr. Neshyba supervised instrumentation of TOTEM buoys with wave and meteorological sensing systems as well as the launching and mooring of the buoys.

Mr. Norman Kujala (Oregon Ocean Supply, Astoria, Oregon) - Mr. Kujala was on subcontract to represent the project in the Columbia River mouth region. In this capacity he observed surf conditions in this area, took photographs of surf conditions from various sites (including the South Jetty tower), coordinated with the Columbia River Bar Pilots to obtain observations of wave conditions over the Columbia River bar and historical data on bar closure periods, and coordinated with the Coast Guard to get observations, information and photographs from helicopters with regard to wave and surf conditions over the bar.

Mr. E. Brackett, Mr. H. Chan and other members of the Astoria Weather Station (National Weather Service) - They provided weather data and background information in support of the project.

The Department of Atmospheric Sciences, OSU - Stimulating discussions with members of the department and the use of the department's microfilm reader were very helpful to the project.

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