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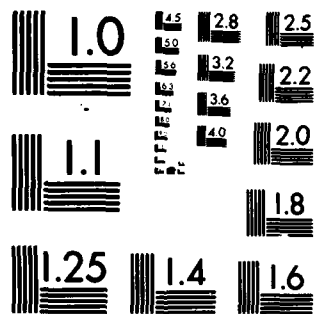
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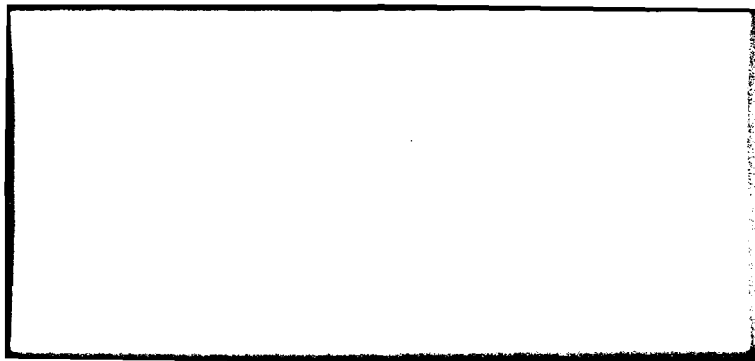
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DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS
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(6) TIDAL MEASUREMENT, ANALYSIS, AND
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by
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and
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(13) Contract N62306-67-C-0122 ✓

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ABSTRACT

For HYSURCH survey operations, tidal analysis is necessary in order to establish a datum plane reference for depth soundings and to provide a basis for long range tide predictions. Because of the brevity of the survey, conventional analysis techniques must be replaced by more approximate methods. The primary sources of tidal energy are reviewed and the accuracy with which their effect can be predicted is estimated. Special attention is given to meteorological interference and local tidal anomalies.

Section II gives a brief description of the instrumentation required for tidal measurements and the telemetry requirements. It includes a survey of existing instrumentation and design recommendations. The need for light weight systems and rapid deployment techniques is emphasized.

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EXPLANATORY NOTE

This is one of a series of Engineering Reports that document the back-ground studies to be used in a system design for HYSURCH (Hydrographic Surveying and Charting System). In general, these reports cover more detail than that finally necessary for a system design. Any subsystem recommendations contained in these reports are to be considered tentative. The reports in this series are.:

- | | |
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| RN-22 | Soundboat Navigation Equipment and Strategy for HYSURCH by John Hovorka |
| RN-23 | The Role of the HYSURCH Survey Ship in the Production of Nautical Charts by Edwin A. Olsson |
| RN-24 | An Investigation of Side-Looking Radar and Laser Fathometers as HYSURCH Sensors by Jack H. Arabian |
| RN-25 | A Computation Center for Compilation, Revision and Presentation of Hydrographic Chart Materials by Edwin A. Olsson |
| RN-27 | Parameters for the Evaluation of Sonar Depth Measurement Systems by Joel B. Searcy |
| RN-28 | Tidal Measurement, Analysis, and Prediction by J. Thomas Egan and Harold L. Jones |
| RN-29 | Applications of Aerial Photography for HYSURCH by A.C. Conrod |
| RN-30 | Sounding Equipment Studies, by Leonard S. Wilk |
- ii -

RN-31 Error Analysis of a Dual-Range Navigation Fix
and Determination of an Optimal Survey Pattern
by Greg Zacharias

RN-32 Tethered Balloons for Sounding Craft Navigation
Aids by Lou C. Lothrop

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TIDE ANALYSIS AND PREDICTION
by
Harold L. Jones

1. INTRODUCTION

The tide analysis requirement for HYSURCH is twofold:

- 1) To supply a reference datum plane for reduction of near shore hydrographic data, and
- 2) To supply ample tidal data to facilitate the publication of tide tables valid for a period of several years.

The maximum tide record obtainable during a Hysurch survey cannot be expected to exceed 7 days; however, these 7 days will not include any major storm activity. Tide predictions resulting from this survey are required to be accurate within 1.5 feet. In order to satisfy this constraint, the reference datum plane of mean sea level must be established to within a few tenths of a foot.

This report contains a general survey of the difficulties involved in meeting such objectives, but concludes that they can be met.

1.1 Terminology

The tidal oscillation is a sinusoid, or summation of sinusoids, caused by the gravitational attraction of the sun and moon. The details of the source of the frequencies involved are reviewed in Section 4.1.

The three primary types of tides are the semi-diurnal tide, the diurnal tide and the mixed tide. The semi-diurnal tide is the most predominant type and is characterized by high tides and low tides alternately occurring every 6.2 hours. The heights of successive high tides and low tides are approximately constant in a given day.

The diurnal tide has only one high tide and one low tide a day spaced approximately 12.4 hours apart.

The mixed type of tide is a superposition of the diurnal and semi-diurnal tides, resulting in the fact that there are two high tides in every 24.8 hour period, but one is considerably higher than the other. The four tides of each day are referred to as higher high water, lower high water, higher low water, and lower low water. The average height differential in the successive high tides is referred to as the diurnal inequality in the high tide.

Because of the relative position of the sun and the moon, the tidal range (difference between high tide and low tide) varies during the lunar month. During the new moon and the full moon, the range is greatest and is referred to as the spring range. During the quarter moon and the three-quarter moon, the range is least and is referred to as the neap range. Mean tide range at a location is a monthly average of the daily range and is the range most often quoted.

The datum planes most commonly establish at a tide station are half-tide level (approximately mean sea level), mean low water, and mean lower low water. The level of half-tide level varies with a maximum period of 19 years. As a consequence, mean low water is defined as the average fall of low water over a period of 19 years. Although a somewhat shorter set of observations can be used, mean low water can not be defined by observation alone with less than one year's observations.

A primary tide station is one which has been in operation for several years and for which a full harmonic analysis has been run. A secondary tide station is a temporary gauge with an expected lifetime of less than a year.

1.3 Datum Plane Determination

The immediate objective of the secondary (portable) tide stations to be used with Hysurch is to supply a datum plane

to which depth soundings in the vicinity of the station may be referenced. Along the east coast of the United States, the reference datum is taken to be mean low water. In areas such as the west coast of the United States where the diurnal inequality is significant, the datum plane is taken to be mean lower low water. In other parts of the world the datum is frequently placed at extreme low water. The main criterion for determining which datum plane to use is that the plane should be low enough that the water depth would not be less than that indicated on the navigation chart except under extreme conditions. Although this requirement implies that it would be convenient to use extreme low water (Low Water Springs) as a reference datum plane, the accuracy with which a datum plane can be established is a function of the number of tide observations available. Since Low Water Springs occur only once every two weeks, mean low water or mean lower low water are more accurately established reference planes for a seven day survey. In general, tides will not fall more than 1 to 2 feet below these planes.

As will be discussed in Section 4.5, the necessary datum plane can be established within one-half foot with a seven day tide record from a secondary station if a primary station is located within a few hundred miles of the survey site, if the tides at the two parts are similar, and if a concurrent tide record is obtainable from the primary station. If the primary tide station is not available, meteorological conditions could increase the error to more than half a foot and seasonal tide variations could quite readily double it.

For a hydrographic survey as currently practiced in the United States, one secondary tide station is often adequate to supply a datum for a stretch of 40 miles of coastline if the tide variations between any two points on the coastline are not large. In general, however, the stations should be spaced no more than 10 to 20 miles apart. The station is usually placed in close proximity to the shore (5 to 20 feet of water at low tide) although it may be placed in deeper water if necessary.

The tidal range is assumed to remain uniform out to a depth of at least several hundred feet and a distance of several miles from shore.

If a tide station is to serve as a datum reference for a large area, care should be taken to insure that it has free communication with tidal waters and that the tide it is recording is representative of the tides in the area which it is servicing. A list of areas which are not suitable for such a purpose is given in Section 5. Supplementary tide gauges should be placed in any of these locations which exist within the survey boundaries.

4. Tide Prediction

The study of tide prediction relative to the Hysurch problem can be resolved to a study of two mutually independent problem areas:

- 1) The degree of precision to which the response of coastal water to the astronomical tide generated in the open sea can be determined and the dependence of this precision upon the length of tide record available, and
- 2) the magnitude of the perturbations of the astronomical tide caused by meteorological conditions and the degree to which the masking effect of these perturbations during a short series of observations can be eliminated.

The conclusions drawn from this study are that tide predictions with an expected error of less than one foot can be generated for a coastal area with a tide record of seven days by means of a comparison of simultaneous observations with a suitable primary tide station. Adverse meteorological conditions for the period of the survey will not affect the accuracy of the comparison markedly; however, the error inherent in the comparison process, when added to the daily weather pattern errors, will yield daily tide predictions somewhat inferior to those at the primary station.

4.1 Astronomical Forces

The principle source of ocean tides is the gravitational attraction of the moon and the sun. At any point on the surface of the earth, these forces are necessarily periodic in nature and their resultant can be represented by a sum of sinusoidal terms of the form:

$$f_n = \sum c_i \cos (a_i t - \phi_i) \quad (1)$$

where c_i , a_i , and ϕ_i are respectively the magnitude, the frequency of oscillation, and the phase lag relative to some arbitrary starting time of the i th component of the gravitational force. For analysis, these force components are considered to be of two types:

- 1) Those terms which are attributable to the independent motion of either the sun or the moon relative to a point on the earth's surface, and
- 2) those terms which reflect the position of the moon relative to the sun and therefore describe the coupled motion of the two bodies.

The periods of the components of the first category vary from 12 hours to 19 years. The most important of these are the lunar and solar semi-diurnal and diurnal components, the lunar month component (27.5 days from perigee to perigee), and the solar year component. A detailed mathematical analysis by Schureman (Ref. 8) indicates that the semi-diurnal forces are greater than the diurnal forces between the latitude 45° North and 45° South. As a consequence, the tides near the equator should be primarily semi-diurnal with the diurnal inequality increasing with increasing latitude. The fact that this is not always true is a function of local topography.

The primary component of the second category has a period of 29.5 days and corresponds to the interval between successive

conjunctions of the sun and the moon. As before, the maximum effect of this force varies with the half period. This component is responsible for producing neap and spring tides.

An additional harmonic contribution to tides is the seasonal (quarter-annual and semi-annual) variation in sea level due to changing meteorological conditions. Because this source has a well defined period and a magnitude of approximately one foot, it is usually treated as the effect of an astronomical force.

In all, there are approximately thirty force components which must be taken into account for accurate tide analyses.

4.2 Ocean Tides

The major oceans of the world respond to this sinusoidal driving force by generating what is best described as a "potential tide" in the open seas. Contrary to the thesis of the equilibrium theory which stated that the earth had a tidal envelope which rotated from east to west about the earth in response to the tide producing forces, the ocean tides appear to consist principally of sets of stationary waves which rotate about tidal nodes in a manner similar to that of tropical storms. Although the existence of these nodes - or areas of null tides - has never been demonstrated, there is evidence that one such point exists in the North Atlantic, one in the South Atlantic and so on.

The magnitude of the ocean tide is not large by coastal tide standards, the maximum range along the equator has been calculated to be 2.5 feet; however, this tide is important in that it is the energy source which provides the pulse that sustains coastal tide oscillations with ranges as great as fifty feet.

4.3 Coastal Tides

In coastal areas which consist of hundreds of miles of straight coastline with no off-shore island chains, or in general in areas where the shoreline is directly accessible by the open sea, local tide effects are small and the tide in such areas is essentially the ocean tide. Examples of such areas are the west coast of the United States (excluding the bay areas) and the Hawaiian Islands. Typical tide ranges in such regions vary from 1.3 feet at Honolulu to 3.6 feet at La Jolla, California with no phase lag behind the ocean tide. The tides vary little in amplitude or in type along the length of the coast line. Although a complete harmonic analysis is still necessary to establish a primary tide station along such a coastline, the predictions from such stations can be extrapolated over several hundred miles without introducing large prediction errors.

The majority of the coastal regions of the world are not topographically simple; but consist of bay, harbors, gulfs, and straits which are partially isolated from the major oceans by land barriers. In such areas, large amounts of tidal water do not flow in and out of the tidal basin on a semi-diurnal basis, but rather a standing oscillation is set up in the smaller body of water which is driven by the ocean tidal oscillations at the mouth of the basin. Although it is obvious that the frequencies present in the standing oscillation must be the same as those present in the ocean tides, nothing can be said of the relative magnitudes of the major tidal components or of the relative phase lags without detailed knowledge of the physical characteristics of the tidal basin in question. Since it is difficult to create an analytical model of the basin adequate for tide prediction, the general procedure is to obtain a tidal record of the area covering a sufficient length of time to facilitate a full harmonic analysis. The predictions from a primary station in such a tidal basin in general cannot be extrapolated past the boundary of the particular tidal basin

and may not be adequate for the entire basin.

4.4 Harmonic Analysis

In addition to the astronomical tidal frequencies, a coastline with expansive shoal areas will generate higher harmonics of the primary components and compound tides which have frequencies equal to various combinations of the primary component frequencies. These shallow water tides may greatly alter the pure sinusoidal appearance of the astronomical tide. In order to obtain an accurate harmonic analysis of the tides at a primary station, each of the potential contributions to the tidal curve must be included in an expression similar to that in Eq. 1. Each of the tidal energy frequencies is referred to as an harmonic constituent.

By means of a least squares approximation to the power spectrum of the observed tidal record, or by an empirical equivalent, a magnitude and a phase can be determined for each harmonic constituent. If each significant constituent is included in the analysis, and if the observed tidal curve covers a sufficient amount of time to eliminate any irregularities, such an analysis will yield highly accurate tide predictions for the immediate vicinity of the tide station.

The major difficulty with performing an harmonic analysis for a tide station is the length of tidal record which must be obtained in order to separate each of the frequencies from the data. Standard procedure for resolving two constituents with similar periods is to choose a length of observation equal to the synodic period of the constituents (i.e. the interval between consecutive conjunctions of like phases). For several of the major diurnal components, the synodic period is six months. Although a paper by Munk (Ref. 6) demonstrates that when the noise level (meteorological interference) is low, successful resolution can be obtained for records somewhat shorter than

the synodic period, this assumption cannot in general be made.

The shortest series for which ESSA is currently able to obtain an harmonic analysis is 29 days. The approach taken is to resolve the five major constituents and then by various assumptions infer 16 others from the nearest primary station. Use of a series shorter than this would yield only marginal results. For a tidal record of seven days or less, the optimal analysis would consist of a comparison of simultaneous observations with a primary station in order to generate a set of correction coefficients (Ref. 1).

Harmonic analyses have been made for the tides of the major ports of the world. In the United States, Western Europe, and Japan; ports at which such analyses have been made are usually no more than 50 to 100 miles apart. In the less advanced or less friendly nations however, the distance between primary ports may be considerably greater. The International Hydrographic Bureau currently lists constituents for 1443 world ports.

The British Admiralty Tide Tables are based on harmonic analyses consisting of sets of 60 constituents. The predictions for the continental United States published by ESSA are based on a set of 37 constituents; however, so small a set has proved inadequate for some ports and in exceptional cases ESSA has used sets as large as 114. Predictions for Anchorage, Alaska (mean range of 25 feet) with a set of 37 constituents were accurate to within a foot of high and low tides only 70% of the time. When the number of constituents was increased to 114, the observed error was less than .6 feet 70% at the time.

It is generally assumed that at primary ports with a full and up-to-date set of constituents, any difference between observed and predicted tides is due to meteorological factors. A comparison made by ESSA (Ref. 1) of six primary stations in the Pacific showed observations to be within .5 feet of predictions 85% of the time and within one foot 98% of the time; however,

all of the stations included has a mean tide range of 3 feet or less. A second sample taken from the files of ESSA consisted of 9 stations including two with tides in the 8 to 15 feet range. The prediction error of high and low tides for these stations was less than one foot in height and .6 hour in time 99% of the time. Data compiled from MacMillan (Ref. 3) and Murray (Ref. 7) for six British stations with mean ranges between 15 and 31 feet showed that despite the difficulties of shallow water tides and North Sea storm surges, high and low tide predictions were accurate within one foot 85% of the time and within 24 minutes 77% of the time.

4.5 Comparison of Simultaneous Observations

The basis for the method of comparison of simultaneous observations is that the tides at two stations located in the same tidal zone should be similar enough that by using a set of simply obtained time and range correction coefficients, the predictions for a primary station may be applied to a secondary station with introduction of negligible errors. As an example, if the tides at the two stations are identical except that the high and low tides occur 30 minutes later at the secondary station, then this correction factor of 30 minutes will yield predictions for the secondary station after an observation period of only a few days which will be equally as accurate as those for the primary station, which may be the result of 19 years of continuous observations.

Unlike a full harmonic analysis, an analysis by comparison of simultaneous observation is a simple task which can be done by hand in a few minutes. For the extent of the survey of an area, a record of high and low waters and their times of occurrence is kept at both stations. In order to insure an accurate record, depth measurements from the tide gauge should be taken at intervals between 30 minutes and an hour to allow accurate smoothing of the curve. At the end of the observations period, the following means are tabulated for each station:

1. mean high tide level (MHW) and mean low tide (MLW)
2. Mean range (MHW-MLW) and half-tide level ($1/2$ MHW + $1/2$ MLW)
3. mean diurnal inequality in the high and the low tide respectively
4. mean time difference in the high and the low tides respectively.

The ratios of the observed ranges, the high tide diurnal inequalities, and the low tide diurnal inequalities; and the differences in the elevations of mean sea level above the respective datum planes are then assumed to be sufficient to yield corrected tide predictions at the secondary station. It should be noted that the mean low tide datum plane for the secondary port is not obtained directly from the seven day observations, but is placed a distance below mean sea level (half-tide level) at the secondary station corresponding to the elevation of mean sea level above the datum at the primary station multiplied by the ratios of the ranges at the two stations. This value may differ from the observed value by several feet.

The accuracy of this method of prediction depends upon the interference of meteorological phenomena and the degree to which the tides at the two stations actually are similar. As is discussed in the next section, meteorological interference during the survey can be ignored subject to certain constraints. The best assurance of similarity in tides will come from a visual comparison of the tide records. If there are two possible primary stations to choose from, such a comparison could be the best means for determining the proper one to use.

A summary of United States tides by Marmer (Ref. 4) indicates that comparisons from one day's observations will generally give mean sea level to within .25 feet, with errors possibly as large as .5 feet. Also, mean high and low waters will be determined to within .5 to 1.0 feet and mean higher high and lower low waters

(if they exist) to within about one foot. The expected errors decrease by a factor of five if one month's observations are used so that with seven days observations, maximum errors of .25 feet, .5 feet, and .5 feet respectively can be assumed.

Unfortunately, no error analysis has been made of daily tide predictions for secondary tide stations although an ESSA verbal contact (Ref. 1) suggests that it is reasonable to expect the error to be less than one foot 75% of the time when the tides at the two stations are similar.

In an attempt to check the validity of the "similar tide" hypothesis, the tide prediction tables published by ESSA for the week of January 1-7, 1967 (Ref. 9), were assumed to be the observed tidal record for the ports of Luta (Darien Ko), China and Chinnampo, Korea. From these "observations" an attempt was made to generate a set of correction coefficients for Chinnampo (secondary station) based on the tides at Luta (primary station). The ports of Luta and Chinnampo were chosen for the test because they are located on the Pacific coast of Asia, an area where the type of tide changes rapidly as one progresses along the coast and because a visual inspection of their tide records indicated that they appeared similar. The ports are located on opposite sides of Korea Bay, 200 miles apart by sea, 350 miles by land. The mean tide ranges for Luta and Chinnampo are 7 feet and 12 feet respectively.

With the aid of a computer, the prediction for Chinnampo based on the comparison of simultaneous observations method were compared to the published predictions based on the harmonic analysis method for the months of July and December, 1967. The maximum prediction error was 1.1 feet in both the high and the low tides with an RMS error of .6 feet. The size of the errors was small for neap tides, but the spring range at Chinnampo was somewhat greater than prediction. The prediction errors are similar for July and December, showing neither seasonal variation nor loss in long range accuracy.

From this example, it appears that the results from the method of comparison of simultaneous observations will be valid over a range of a few hundred miles as long as both stations are in the same tidal basin; however, this is strictly dependent upon local conditions and will vary between localities.

4.6 Meteorological Effects

The record of meteorological effects on tides is obtained by subtracting the predicted astronomical tide from the observed tide record - the residue being termed the daily value of sea level. The day to day variation of sea level determined in this manner is assumed to be directly attributed to meteorological phenomena. A thorough study by Groves (Ref. 2) of the sea level records of 20 ports on both coasts of the United States, the coast of Alaska, and several Pacific Island groups uncovered three basic facts:

- 1) The RMS variation of mean sea level is half a foot with peak day to day variations of 1 1/2 feet.
- 2) The peak spectral energy in the record has a period of 3 to 4 days.
- 3) There is a coherency between adjacent stations which persists up to several hundred miles.

Because of the long period of the meteorological forces, the daily tide range is not affected, but both high and low tides are displaced in the same direction. Subsequent study of the records used by Groves indicates that sea level for a seven day period can average as much as one foot above normal. The meteorological perturbations are due primarily to two factors; variations in the atmospheric pressure over the coastal area and strong onshore or offshore winds. Of these two, the effect of atmospheric pressure is the more readily analyzable. The ocean tends to act as an inverted water barometer. If atmospheric pressure at a coastal point is 1 millibar above the average pressure on the entire ocean, sea level at that point will be depressed 1 cm. When the sea level records were corrected by Groves for this factor, the RMS variation of the

records was reduced by one-half to a value of .25 feet. It should be assumed that such pressure corrections would be made to the tidal records at both the primary and the secondary tide stations before they are submitted for analysis. The corrections, however, should be made on a daily average rather than on an hourly basis.

The effect of winds on the daily value of sea level is assumed to be the only source of variation in the pressure-corrected sea level records. No more analytic statement can be made than that an onshore wind tends to raise the value of daily sea level and an offshore wind tends to suppress it. The effect of local winds appears to be greatest at;

- 1) points where there are strong winds
- 2) the edge of continents
- 3) points where there are extensive shoal regions.

Although the effect of local winds may degrade the accuracy of daily tide predictions, it does not appear to be significant in the determination of datum planes or of correction coefficients. Besides the long range coherence mentioned earlier, Groves noted that with respect to the local wind effects, small scale local topography appeared irrelevant. This means that if the primary station is on the same side of the tidal basin as the secondary station and if the shoal water conditions are similar (which they must be if the tides are similar) any wind induced sea level elevation at the primary station can be used as a correction factor for the secondary station with only a small induced error. As a check, however, a daily record of wind direction and velocity at both stations should be kept and any large or persistent discrepancy between the two should be annotated on the charts.

The only successful approach to the prediction of wind induced errors in tide prediction has been the empirical generation of nomograms; examples of which are given by Miller (Ref. 5) and MacMillan (Ref. 3). Using the Miller nomogram for Atlantic City, the maximum elevation or depression of sea level for a steady 34 kt wind is found to be 1.5 feet, although storm surges in excess of

4 feet have been known to occur. The conditions at Atlantic City are extreme and for most coastlines the expected error would be no more than half that figure.

The length of tide record required to produce these nomograms (several months to a year) precludes their generation by Hysurch. For surveyed areas, wind induced errors in prediction will be uncompensated for and in shoal areas, this should be clearly indicated on all published charts.

5. Special Tidal Phenomena

As mentioned in Section 3, there are a number of tide related phenomena which may so alter the basic tidal oscillation along a shoreline as to make a particular location unsuitable as a datum plane reference for a large area survey. Although these special tide effects may be significant over an area of several square miles along the shoreline or inland from the shoreline, they are the consequence of specific shoreline configurations and are not representative of the tidal oscillations at a distance from shore. Tides in such areas generally change rapidly as a function of position and secondary tide stations should be placed no more than one mile apart.

The coastline configurations responsible for these special tidal effects are readily identifiable on coastal charts. A partial list includes:

- a) The mouth and upper reaches of tidal rivers. Variations in the volume of drainage of a river can become an important pseudo-tidal constituent. After heavy rains, high tide can be raised several feet and shifted several hours at any point along the river .
- b) Small bays connecting to the tidal basin through narrow openings. The tide range in such bays is much less than that of the tidal basin.

- c) Straits and channels connecting two bodies of water with different tide ranges and times of high tide. Examples of such areas are the channel north of Vancouver Island, British Columbia, and Woods Hole, Massachusetts. The tides and tide currents in such areas are quite complicated and may vary greatly over a few hundred yards.
- d) Converging or V-shaped estuaries. Tide ranges in these areas are greater than in the main basin due to the funneling of tidal energy.
- e) Rectangular estuaries near resonance. If the natural frequency of such an estuary is near the frequency of a major tidal constituent, the range will be greater than that in other areas and the type of tide will be somewhat different.

Tide prediction in these areas represents a more difficult problem than prediction in the more open regions. If the density of secondary tide stations is sufficient, however, prediction errors will not be much greater than along the open coastline.

6. Conclusion

For a hydrographic survey of a 100 mile section of coastline, it is necessary to establish a series of secondary tide stations in shallow water in order to establish datum reference planes (mean low water or mean lower low water). These stations should be spaced no more than 10 to 20 miles apart. For certain special coastline features, secondary stations should be as close as one mile apart. It is desirable that at least one primary station be included in the survey area. If no such station exists, tidal data concurrent with the survey period must be obtained from the primary stations nearest the survey region.

Establishment of a reference datum plane for a survey area does not appear to pose a significant problem if care is taken to exclude meteorological interference from the comparison with the primary station. A conservative estimate is that mean low water can

be established to within one-half foot for a seven day survey period.

At primary tide stations, tide prediction errors are due exclusively to meteorological disturbances. It is reasonable to expect that on a world-wide basis, predictions for high and low tides for such stations will be accurate within one foot and 30 minutes no less than 80% of the time. In general, the accuracy will be considerably better than this.

Predictions for secondary ports are much more difficult to generalize from because of the difficulties involved with finding primary stations with similar tides. In most areas, the errors will be comparable to, but slightly greater than, those for the corresponding primary station. In some areas of the world, however, the errors could be significantly larger. An estimate of the accuracy of the predictions for secondary ports can be obtained by comparing the tide curves of the primary stations along the length of the coast. If the tide curves for two adjacent primary stations differ drastically, secondary station predictions for the region between them may be marginal. Likewise, in areas where special tidal effects are dominant, prediction errors may be larger. In these instances, it is desirable to leave the tide gauges intact longer than the seven day survey period if this is at all feasible.

The difficulty of the prediction problem on a world-wide basis appears to be the establishment and the maintenance of a sufficient number of primary tide stations. With this respect, one of the long range objectives of Hysurch should be the establishment of a world-wide primary tide station grid. In regions where there are not presently a sufficient number of such primary stations for accurate secondary station predictions, they should be established now in order that they would be available if needed.

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INSTRUMENTATION FOR TIDAL MEASUREMENTS

by
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1. DEFINITION OF HYSURCH REQUIREMENTS

The immediate design goal of this phase of HYSURCH is to recommend reliable instrumentation which will furnish tidal current velocity, direction, and change in depth information for a period of 1 to 7 days after deployment of instrumented buoys. Each unit must telemeter an identifying number and measured parameters to a data processing ship up to 50 miles away.

Typically some 10 to 30 buoys will be deployed over an area of some 100 square miles. It is desirable to disperse all instruments within a few hours and to retrieve them at a later date. It is anticipated that these moored buoy packages will be dropped from a fast boat and will extend themselves reliably into the operating condition. Preferably the weight of each package should not exceed 100 pounds so that 2 men can toss it overboard.

2. SURVEY OF AVAILABLE SENSORS

A fairly extensive survey was made of the commercially available instruments to be used for tidal measurements.

The most widely used type of current sensor is the savonius rotor. This instrument will read current flowing in any horizontal direction as a positive value. In itself this is not harmful because a rudder would be used to orient the instrument housing and therefore the compass reference for proper directional indication. In practice a sensor suspended about 6 feet below the water surface will experience a 1 to .1 Hz elliptical motion, with respect to the surrounding water due to surface wave action. In the absence of a substantial average flow direction the rudder will have a meaningless response to an oscillating current.

This project will require a current velocity meter designed to ignore all off axis components of relative water motion and must indicate symmetrically the directional sense of all on axis flow components.

3. RECOMMENDED INSTRUMENTATION

This effort has been discussed with a number of manufacturers and users of oceanographic equipment. They have been very helpful in arriving at the following design recommendations although they seem to share a certain lack of enthusiasm for our package launching technique and weight suggestions as well as the sea state 3 requirement.

Obviously weight requirements and skill in protective packaging can be traded off with deployment and retrieval time and effort.

The sea state 3 requirement presumably refers to the open ocean and is concerned with boat handling and servicing. This condition should moderate in shallower waters where tidal measurements will be required. The mooring designs shown in Figures 1 and 2 are tentative but will be used as a starting point for further discussions with the instrument manufacturers.

At this time we recommend a ducted fan type of velocity sensor and a magnetic compass with a potentiometer output combined into one housing. A small rudder on the end of a long arm will be used to align the sensor housing with the current flow. This configuration will give a relatively long time constant which will minimize the effect of the wave induced directional errors. See Figure 1.

The ducted fan-with the help of some electronics-will count the difference between the numbers of positive and negative pulses in a given interval-typically 2 minutes. This technique will give an average current velocity reading. The pulse count should vary from 20 to 1000 counts in the .2 to 10 knot range. This count must be stored for later transmission as required within a 1 second period.

The liquid damped magnetic compass is to be designed to drive a continuous turn ultra low torque potentiometer. This is the simplest compass reading system and is widely used but it does not lend itself to averaging a number of readings. One instantaneous reading will be made "on the line" as required.

The change in depth sensor may consist of a dial type pressure gage with a range typically of 15 psi or when used as a zero center gage ± 17 ft. of water. An ultra low torque potentiometer will turn with the needle. As the sensor sinks to its operating place on the bottom a slack rubber diaphragm will allow air pressure inside and outside the bourdon tube to come to ambient pressure. After about 1/2 hour on the bottom a corrosive link will fail and allow a valve to seal the passage to the inside of the bourdon tube. This delay time is used to establish thermal equilibrium. Under certain conditions this instrument would respond to pressure changes due to surface waves so a pneumatic resistance will be used in the passageway to the outside of the sensing tube to filter out the higher frequency pressure changes. A relief valve will be required to protect the instrument when it is raised to the surface. It is expected that this sensor will not be used at depths greater than 100 ft.

At this time it appears that an accurate escapement type clock and a small D.C. time switch mounted in each buoy would be feasible. Typically this system would allot the transmitter 5 sec. on time every 10 minutes and, if properly sequenced before launch, would allow some 30 buoys to share the same frequency and data processing facilities.

The ducted fan sensors and timers are commercially available items. The compass and change in depth sensors are modifications of well proven designs.

3.1 PERFORMANCE REQUIREMENT

The instrument accuracy specifications mentioned in the work statement would seem justifiable in deep sea oceanography but seem too demanding for the needs of this phase of HYSURCH.

If we consider the end product as navigational information for power boats and also consider the very limited sampling of data-time wise, area wise, season wise and weather wise, we would save considerable time and money and increase the reliability by easing the specifications.

The following recommendations are suggested as being adequate for the HYSURCH tidal measurement requirements:

- 1) The current velocity sensor is to have an accuracy within .3 knots in the range of .3 to 7 knots. For a directional symmetry test the sensor is to be advanced through stationary water at .6 knot for 30 ft. and reversed at the same rate, distance and accelerations and is to show an integrated distance error of less than 2 ft. The above tests are to be conducted in a tow tank without waves.
- 2) The compass assembly is to be gimballed on at least 1 axis and in the absence of vibration is to indicate magnetic north within 15° . This test is to be conducted in an area essentially free of man made magnetic influences.
- 3) The change in depth sensor must have a useful tidal range of 16 ft. regardless of the tide condition at time of launch. The accuracy must be within .3 ft. A damper or filter must be used which will cause a step increase in pressure equivalent to 5 ft. of water to reach 90% of the new value in 5 to 15 minutes.
- 4) The buoy system must be designed and proportioned to maintain its moored position and operate without mechanical failure in a sea state 3 condition. This condition is to be met without supplemental anchor weights.

4. TELEMETRY REQUIREMENTS

The telemetry details have yet to be frozen. The decision to use clock in each buoy instead of an interrogating system will require further study.

5. CONCLUSIONS

In general the measurement of the 3 parameters mentioned are well within present instrumentation capabilities. The presence of waves-in particular sea state 3 waves-will degrade the accuracy of all 3 sensors. The performance recommendations were suggested as being entirely adequate for the project requirement and will make all instruments and components interchangeable with a minimum compensation.

The packaging and launching technique will require further study. This is the one area where creative design is required because much more time or effort will be required if the above launching recommendations are not followed.

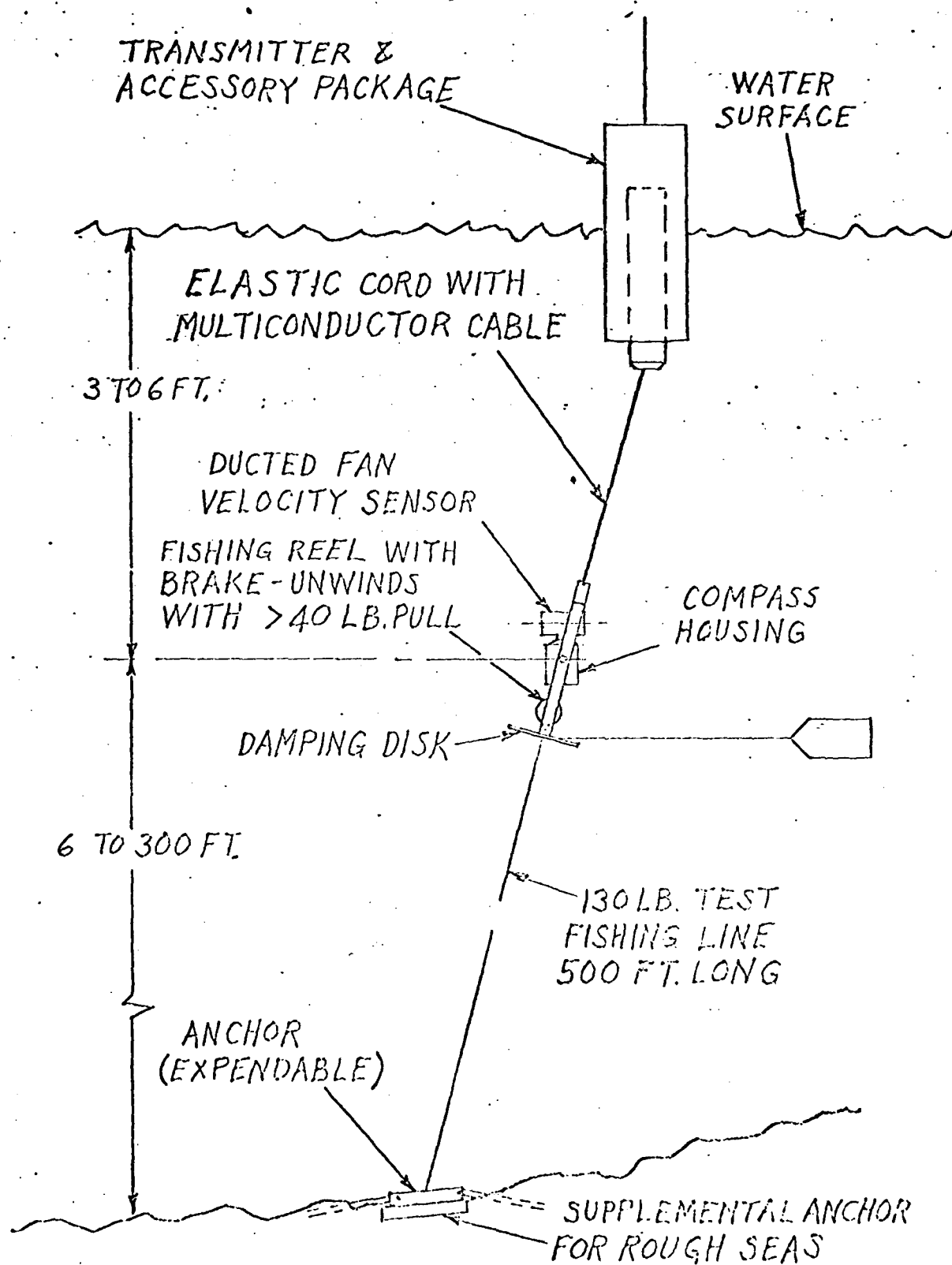


FIG. 1 TIDAL CURRENT SENSOR

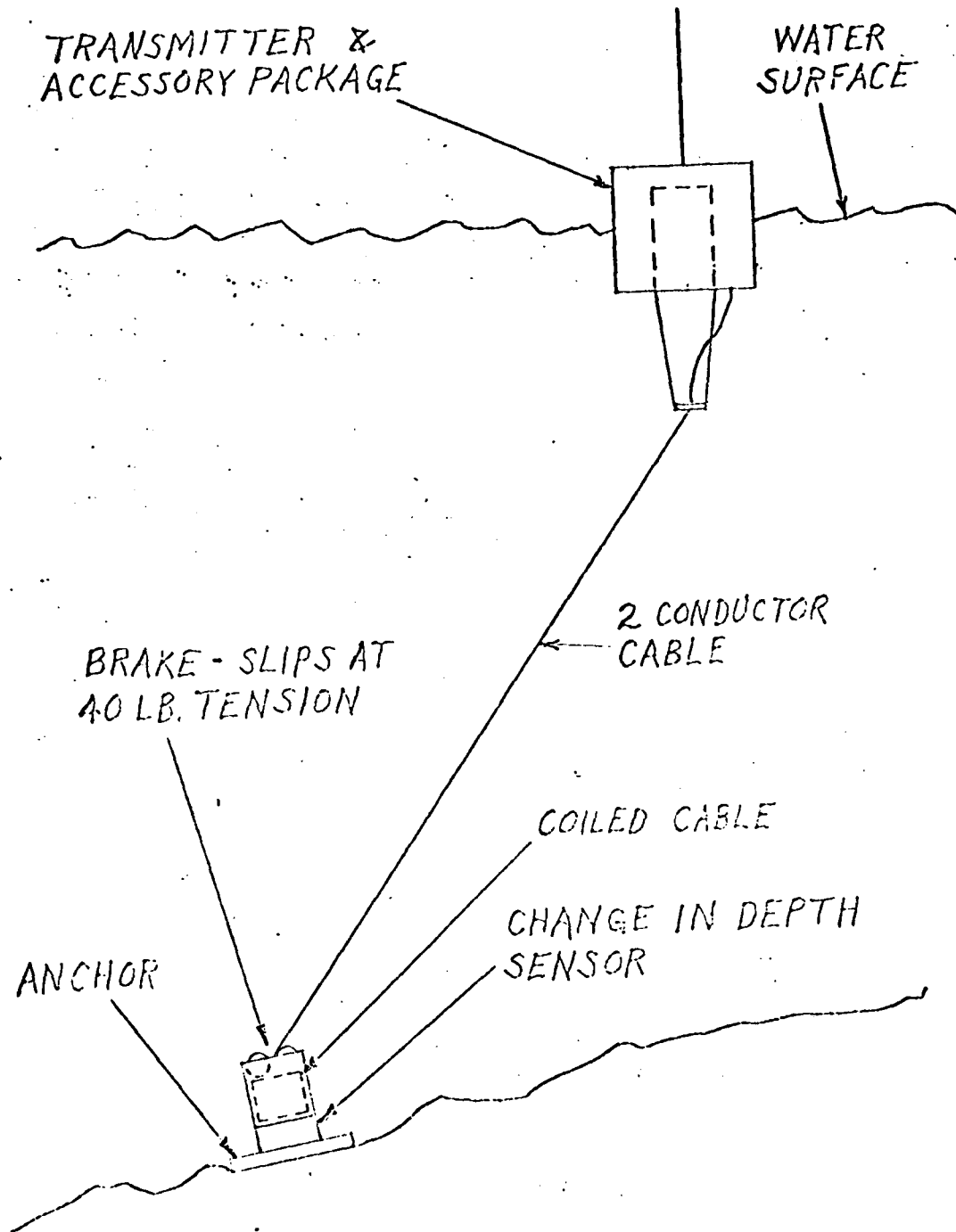


FIG. 2 TIDE METER