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PRELIMINARY REPORT ON A FORTRAN IV COMPUTER PROGRAM FOR THE TWO-DIMENSIONAL DYNAMIC BEHAVIOR OF GENERAL OCEAN CABLE SYSTEMS

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Naval Ship Research and Development Center
Bethesda, Maryland

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by

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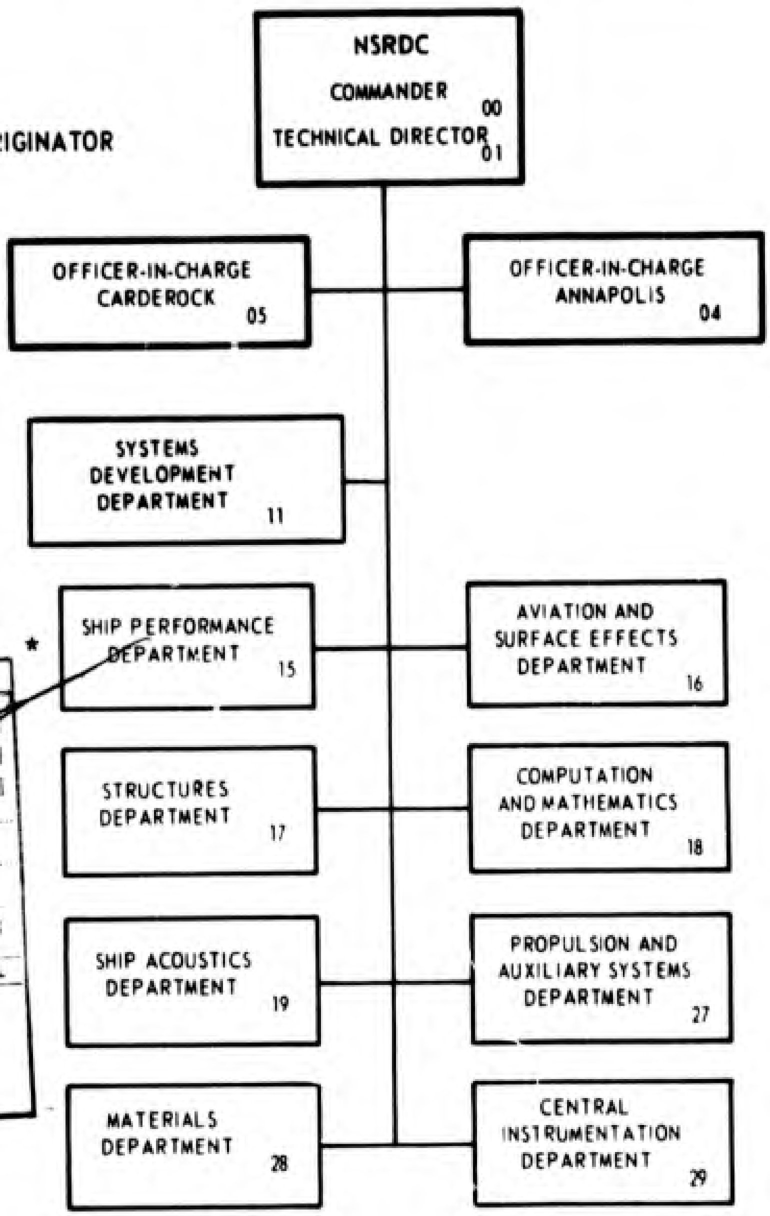

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The present report describes program CABUOY, which analyzes in some detai the two-dimensional dynamic behavior of general ocean cable systems consisting of a surface buoy, connecting cable, and intermediate bodies. The report briefly presents the calculations which are carried out in the program, gives computer time requirements for several cable cases, and outlines some relatively small additional areas of work. Detailed input instructions are given in the Appendix.

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ABSTRACT

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ADMINISTRATIVE INFORMATION

The work described in this report was authorized by the Naval Air Development Center under Project Order No. 4-0601 dated 5 March 1974. The work was performed under internal Work Unit 1552-130.

INTRODUCTION

The study of the dynamic motion characteristics of cable systems is currently an area of extreme interest. For example, in the past two years at least three major surveys of cable dynamics studies have been written.[1,2,3*]

An ocean cable system will in general consist of the following three components:

(a) A ship or surface float at the upper end

(b) A cable which may vary in its properties along its length

(c) Intermediate bodies along the cable, including the possibility of a body at the lower end.

Previous studies have usually focused on only one of the above components. For example, in many studies, the principal emphasis is on the dynamic characteristics of the cable itself. At the ends of the cable, the conditions are either those of prescribed motions or simple representations of the surface buoy or lower body. It appears that these studies were carried out for the principal purpose of demonstrating the feasibility of a particular method of solving for the dynamic characteristics of the cable. Choo and Casarella[2] discuss the merits and demerits of the three principal methods: the linearized frequency-domain method, method of characteristics, and finite element method. In other studies, the principal emphasis is on the dynamic characteristics of the surface buoy or the lower body. The effect of the cable is then approximated in various ways.

*References are listed on page 19.

It is clear that the above types of studies are suitable only for analyzing the dynamic characteristics of particular types of cable systems. Also, only the dynamic characteristics of certain components of the cable system are accurately described.

The present report describes program CABUOY, which analyzes in some detail the two-dimensional dynamic behavior of all three components of a general cable system. While the program was developed principally to analyze the dynamic behavior of sonobuoy systems, for which it is of interest to know the dynamic behavior of the surface buoy, connecting cable, and lower acoustic detection units, its great generality and versatility will make it a useful program for a wide variety of cable systems.

The report briefly describes the calculations which are carried out in the program. These include the calculations for the steady-state configuration, the modeling of the surface waves, and the motions of the surface buoy, cable, and intermediate bodies. A more complete description of these calculations will be given in the final report. Computer time requirements for several cable cases are presented. Some relatively small additional areas of work which would make the program even more useful are outlined. The Appendix lists the Fortran READ statements by means of which data are entered into the program as well as the definition of the input variables contained in these READ statements.

The input instructions given in the Appendix illustrate the great generality and versatility of the computer program. The characteristics of each component of the ocean surface waves may be specified by the user or may be internally generated by the program by using the Pierson-Moskowitz spectrum. The surface buoy at the top of the cable may be a prolate or oblate spheriod of size small compared to the wavelengths of the ocean waves or may be a spar buoy of any size. The reasons for the particular choices of buoy sizes and shapes are given in the section on surface buoys. Alternatively, motions may be prescribed at the upper end. The user determines the accuracy to which he wishes to model the dynamic behavior of the cable by specifying the total number of cable segments as well as the length of each segment. Several different formulations are given for the added mass and drag coefficients of the intermediate bodies.

SUMMARY OF CALCULATIONS

STEADY-STATE CALCULATIONS

The program first calculates the configuration of the cable system due to a steady-state current alone, in the absence of any time dependent excitation due to surface waves. The differential equations for the steady-state configuration of the cable are derived for the coordinate system shown in Figure 1 and are essentially a two-dimensional specialization of the equations contained in References 4 and 5.

Since sonobuoy systems usually have round cables, the cable is taken to be round in the present study for the sake of simplicity. Thus, the normal and tangential drags are taken to be respectively proportional to the squares of the velocities normal and tangential to the cable.[6]

An area of difference between the present formulation and that contained in References 4 and 5 lies in the tension-strain relation. Whereas this relation was previously read into the program as a table of values, the Appendix shows that the tension is expressed as a power of the strain in the present formulation. This still allows for a nonlinear tension-strain relationship while minimizing the amount of input data.

The present program assumes conditions to be known at the upper end of the cable and integrates the differential equations of equilibrium down the cable. At an intermediate body the integration must be interrupted and the unknown cable variables below the body must be related to the known variables above the body. The equations used to relate the cable variables below the body to the cable variables above the body are essentially the two-dimensional specialization of the equations contained in References 4 and 5.

OCEAN SURFACE WAVES

The Appendix shows that the ocean waves are modeled by a sum of sinusoidal components. The user may specify the total number of components N, and the amplitude a_{wi}, the frequency f_{wi}, and the phase angle θ_{wi} of each component. Alternatively, the user may let the program internally compute a_{wi} and θ_{wi}. The θ_{wi} are simply taken to be uniformly spaced between 0 and 360 degrees. The a_{wi} are computed from the Pierson-Moskowitz energy sea spectrum in the form given by Frank and Salvesen.[7] The spectrum in this form was recommended by the 11th International Towing Tank Conference (1966) in Tokyo for computations "when information on typical sea spectra is not available".[7] Other forms for the sea spectrum can, of course, be conveniently incorporated into the program.

SURFACE BUOY EQUATIONS

The program allows the user the option of prescribing the motion of the surface buoy or describing its motion by means of differential equations of motion.

Prescribed Motion

If the surface buoy or ship is of sufficiently large size such that its motions are not appreciably affected by the presence of the cable, these motions may be calculated separately and then entered as an input into the present program. There are a number of programs available to calculate the pitch and heave motion responses of surface ships; for example, the Frank Close-Fit Ship-Motion Computer Program.[7] Another application where this approach is valid is in laboratory simulations of cable dynamics where the motions at the upper end of the cable are often prescribed. The Appendix shows that the prescribed motions are assumed to consist of a sum of sinusoidal motions in the x and y directions.

Differential Equations of Motion

It is well known that the added mass and damping coefficients of surface buoys are, in general, functions of the frequency of the oscillation.[8,9] In the time domain, this requires the solution of integro-differential equations which contain convolution integrals. Alternatively, if the frequency-dependent coefficients can be expressed as simple polynomials of the frequency, the integro-differential equations may be replaced by a set of higher-order differential equations.[8] In either case, the solutions are complex and/or time consuming in the time domain. Thus, surface ship motions have usually been solved in the frequency domain. In this approach, the steady-state harmonic response is obtained for each frequency component of the exciting surface waves. The total response to the sum of the individual wave components is then obtained by linear superposition. Experiments have shown that this procedure generally yields satisfactory results for the case of the pitch and heave motions of surface ships.

In view of the above difficulties concerning the solution of the buoy equations in the time domain, studies on the motion of cable-buoy systems have usually also used the frequency domain approach. Perhaps the most comprehensive of these studies is the computer program developed by Goodman et al.,[10] in which four different buoy shapes are considered. In addition to facilitating the solution for general buoy shapes, the frequency domain approach has the additional advantages of immediately giving the steady-state harmonic response (without the need of waiting for the transient response to die down) and also results in considerable savings of the computer time required to obtain the cable motions.[11] However, this approach has the drawbacks of neglecting all the nonlinearities and also assuming all the dynamic response variables to be small compared to their steady-state values. This approach would not be able to predict, for example, the large dynamic snap loads which occur when the cable goes slack.

In view of the above drawbacks and also in view of the existence of the comprehensive frequency domain computer program described in Reference 10, it was decided to use a time domain approach in the present study. In order to make this a feasible approach it was important to find classes of buoys which did not have frequency-dependent added mass and damping coefficients. A search through the literature revealed two such classes of buoys: spar buoys[12,13] and small buoys. Spar buoys are buoys with circular cross-sections and large draft-to-diameter ratios H/b. Due to the slenderness of these buoys, their added inertia terms are essentially those for infinite fluid, and the frequency-dependent wave damping coefficients are zero to first order approximation.[12] The other class corresponds to buoys whose typical dimension a is so small compared to the ocean wavelengths λ such that the reduced frequency $\bar{\sigma}$ given by

$$\bar{\sigma} = 2\pi \frac{a}{\lambda} << 1 \tag{1}$$

for the range of λ's corresponding to ocean waves of interest. For surface buoys of sonobuoy systems, whose typical dimension is of the order of 1 foot, the above condition holds for the large majority of sea states. When Equation (1) holds, the wave damping terms go to zero and the added inertia terms for $\bar{\sigma} = 0$ may be used. In this case, the ocean surface behaves essentially as a rigid plane,[14] and the added mass in surge is equal to the infinite fluid value. Since the added mass coefficients for pitch and heave have been studied for prolate and oblate spheroids of various aspect ratios,[15-18] it was decided to represent the small buoys by prolate and oblate spheroids. Both types of spheroids are characterized by having two of their three axes equal in length. The limiting cases for a prolate spheroid are a long thin cylinder and a sphere while the limiting cases for an oblate spheroid are a thin circular disk and again a sphere. From these limiting cases it can be seen that prolate and oblate spheroids can be used to generate a wide range of shapes.

For both the spar and spheroidal buoy cases, three second-order differential equations are written for the surge ξ, heave ζ, and pitch ψ. The equations for surge and heave contain the following forces:

1. Inertia force = (mass+added mass) X acceleration
2. Froude-Krylov force due to the exciting ocean waves*
3. Viscous drag
4. Cable tension force
5. Wind loading
6. Restoring buoyancy forces

The equation for pitch contains similar terms expressed as moments.

These equations have been written assuming the pitch angle ψ to be small such that

$$\sin \psi \simeq \psi \qquad (2a)$$

$$\cos \psi \simeq 1 \qquad (2b)$$

Under static conditions, the submerged volume V must support both the weight in air of the buoy, mg, and the vertical component of the steady-state tension, Tys

*For the two classes of buoys considered in the present study, slender spar buoys and small buoys with $\bar{\sigma} \ll 1$, the diffracted waves may be taken to be negligible compared to the incident waves.[12,14] In this case, the exciting forces are computed by using the Froude-Krylov approximation, wherein the pressure distribution of the incident wave system is assumed to be unaffected by the presence of the buoy.

$$\rho\, gV = mg + Tys \qquad (3a)$$

$$V = \frac{m}{\rho} + \frac{Tys}{\rho g} \qquad (3b)$$

If the input dimensions for the draft and cross-sectional areas of the buoy are such that the submerged volume does not equal the value given in Equation (3b) the program internally multiplies the cross-sectional areas by a constant factor such that the submerged volume becomes exactly equal to the value given by this equation.

For the spar buoy, the added mass coefficients for surge and pitch are obtained directly from Newman.[12] Newman takes the buoy to be sufficiently slender so that its added mass in heave can be neglected. Adee and Bai[19] experimentally show, for the case of a circular cylinder, that it is a more accurate approximation to use as the value for the added mass, one-half the added mass of a circular disk (with the same diameter as that of the cylinder) heaving in infinite fluid. This approximation has been incorporated in the present formulation by taking the diameter of the disk to be the mean diameter of the spar buoy.

For the spheroidal buoys, the added mass coefficients are given for the case where the waterplane cross-section corresponds to the maximum cross-section of the buoy, i.e., the buoy is exactly half submerged and half exposed to air. This is the usual assumption made in the spheroidal buoy studies.[15-18] The added mass coefficients are given in terms of modifying factors multiplying the infinite fluid values, which are obtained from Kennard.[20]

In order to determine the modifying factors to account for the free surface effect, the applicable literature on spheroidal buoys[15-18] was surveyed. At the limit of zero reduced frequency $\bar{\sigma}$, the ratios of the added mass coefficients in heave and pitch to their respective values in infinite fluid were determined for various values of the draft to waterplane diameter ratio, H/B. (As mentioned previously, the added mass in surge is identical to its infinite fluid value at zero reduced frequency). A quadratic equation was used to describe these ratios in the range $0 \leq H/b \leq 5$. For $H/b \geq 5$, it is somewhat arbitrarily assumed that the buoy may be considered as a spar buoy for which, as previously pointed out, the added mass coefficients are identical to the infinite fluid values.

CABLE EQUATIONS

A finite element approach is used to model the cable. This approach facilitates the modeling of nonuniform properties along the cable as well as the presence of intermediate bodies. The continuous cable is divided into a number of massless straight elastic segments. The mass, weight, and drag acting on each cable segment is divided equally between the two nodes at the ends of the segment.

Preliminary Approaches

Before deciding on the final formulation, a number of preliminary approaches for obtaining the differential equations of motion were explored. In one approach, the equations were formulated in a coordinate system aligned with the cable segment. In this approach, the two unknowns are the inclination and stretch of each segment. This is the most natural way of describing the configuration of a segment. In addition, certain cable forces such as the tension, added inertia, and drag forces are most conveniently expressed in directions normal and tangential to a cable segment. However, in the presence of intermediate bodies along the cable, for which the inertia and drag forces are most conveniently expressed in the spatial x and y directions, the conversions required to relate the body forces to the cable coordinate system greatly complicate the equations.

The results of Reference 21, which show that relatively few segments are required to accurately describe the overall configuration of a cable, suggested a second novel approach. In this approach, the cable was conventionally divided into a number of straight segments and two differential equations in the x and y directions were written for the nodes at the ends of the segments. However, each straight segment was subdivided into a number of intermediate nodes. Since these intermediate nodes were forced to move along the straight cable segment, only one differential equation was needed to describe the longitudinal motion of these nodes. The principal intention of this approach was to have the end nodes describe the overall cable configuration and the intermediate nodes describe the variation of tension along a cable segment. There was not sufficient time in the present study to fully explore this approach. However, it was found that there was a certain amount of bookkeeping required in the program to differentiate between the "end" and "intermediate" nodes. Also, while this approach reduced the total number of differential equations from that required by more conventional approaches, the integration time step still depends on the distance between intermediate nodes and the elastic modulus of the cable. For short distances and nearly inextensible cables, integration step sizes become very small, which in turn lead to large computer times.

Final Formulation

In view of the above, each cable segment was kept free of intermediate nodes and two second-order differential equations in the x and y directions were written for the nodes at the ends of the segments. These equations contain the following terms:

1. Inertia of cable
2. Inertia of intermediate body
3. Cable tension due to stretch
4. Internal damping of cable due to strain rate
5. Drag acting on intermediate body
6. Tangential drag acting on cable
7. Normal drag acting on cable
8. Weight in water of cable
9. Weight in water of intermediate body

INTERMEDIATE BODIES

Constant Coefficients

The inertia forces in the x and y directions are expressed as the virtual mass times the acceleration in these directions, where the virtual mass is the sum of the mass of the body and the constant infinite fluid added mass.

The drag forces are more difficult to describe. It is well known that the resultant force acting on a body in a fluid flow varies with the shape of the body and the orientation of the body relative to the flow. In the present study, the following two formulations are used. In one formulation, the resultant drag is assumed to be parallel to the resultant fluid velocity relative to the body. Components are then taken in the x and y directions based on the magnitudes of the velocities in these directions. Also, a correction is made to account for differences in the drag areas in the two directions. This approach is exact for spheres and is approximately correct for other blunt shapes, such as near-cubes or circular cylinders with length to diameter ratios of approximately 1, for which the drag areas are approximately the same for any flow direction.[22] In the second approach, the drag forces in the x and y directions are taken to be proportional to the squares of the components of the fluid velocity in these respective directions. This is a good approximation for long cylinders or thin disks with axes parallel to the x or y directions. In these cases, the drag in one direction is essentially pressure drag while the drag in the other direction is essentially due to friction.

Variable Coefficients for Circular Disk

When a body is executing dynamic oscillations such that it periodically traverses its own wake, the added mass and drag coefficients are more correctly expressed as functions of the motion.[23] For the case of a circular disk, which is commonly used in sonobuoy systems to damp out the motions of the lower acoustic units, the user may either use the constant coefficient approach described above or have the added mass and drag coefficients computed internally by the program based on the experimental relationships between these coefficients and the motion of the disk given in Reference 23.

COMPUTER TIME REQUIREMENTS AND COSTS

On the CDC 6600 currently being used at the Center, the program requires approximately 39 seconds to compile. The table below gives the execution times (ET) and total computer cost for various cases. In all cases shown in the table, the dynamic motions were computed for 21 seconds of real time. In this table, priority P4 is the highest computer priority (CP) and P2 is overnight priority. The number of segments NCAB for the free-floating (FF) cases included the fictitious segment connecting the lower unit to the ocean bottom. C1(K) refers to the force required to double the unstressed length of the cable (strain=1). NSW refers to the number of components of the surface waves.

Cable System	NCAB	NSW	Surface Motion	Cl(K) (lb)	ET (sec)	CP	Total Cost ($)
FF	2	1	Prescribed	2×10^4	7.2	P3	7.21
FF	3	1	Prescribed	2×10^4	21.1	P4	10.39
FF	5	1	Prescribed	2×10^4	50.3	P2	9.69
FF	3	1	Prescribed	2×10^5	28.6	P2	7.79
FF	3	1	Prescribed	2×10^6	53.1	P3	12.19
FF	3	8	Prescribed	2×10^4	39.4	P2	8.76
Moored	3	1	Prescribed	2×10^4	21.0	P2	7.16
Moored	3	1	Spar buoy	2×10^4	27.2	P3	9.37
Moored	3	1	Prolate spheroidal buoy	2×10^4	23.0	P3	8.92

The first three entries of the above table show that ET is approximately proportional to the square of NCAB. The second, fourth, and fifth entries show that ET increases with increasing values of the elastic modulus. The second and sixth entries show that ET is approximately doubled when 8 surface wave components are considered instead of 1. The last three entries show that there is only a relatively small increase in ET when a surface buoy is considered at the top of the cable instead of prescribed motion.

AREAS OF FURTHER WORK

It is felt that the following relatively small tasks will not only improve the accuracy of the computer program but also make it more useful.

1. The program presently takes conditions to be known at the upper end of the cable in order to perform the steady-state calculations. In towing applications, it is more convenient to take conditions to be known at the lower end while in other applications[24,25] iteration techniques must be used. Thus, it is of interest to expand the steady-state capabilities of the program in order to make it a more self-contained program.

2. The steady-state and dynamic equations for the surface buoy are presently written assuming the pitch angle ψ to be small. In some computer runs, it has been observed that transient motions may lead to large values of ψ. Thus, the buoy equations should be rewritten for arbitrary values of ψ.

3. The added inertia terms for the spheroidal buoys are presently formulated for the case where the waterplane occurs at the maximum cross-section of the buoy. It is of interest to make suitable corrections for other waterplanes.

4. The computer program should be run over a wider range of cable and buoy parameters to more thoroughly assess its capabilities and computer time requirements.

ACKNOWLEDGMENTS

The author wishes to thank Mr. Dennis E. Hannan who developed a preliminary computer program for the dynamic cable motions. He also wishes to thank Mr. Vincent J. Monacella and Dr. J. Nicholas Newman of the Massachusetts Institute of Technology for helpful technical discussions concerning formulations for the surface buoy.

APPENDIX - INPUT INSTRUCTIONS

READ STATEMENTS

Input data are entered into the program by means of the following READ statements contained in the MAIN Program and in Subroutine BUOY.

MAIN Program

```
READ (5,1) NCASES
DO 1000 MC=1, NCASES
READ(5,1) NSM, NSW,NCAB,NCUR
READ(5,2) (FSM (K),K=1, NSM)
READ(5,2) (AXSM(K),K=1,NSM)
READ(5,2) (AYSM(K),K=1,NSM
READ(5,2) (FIDSM(K),K=1,NSM)
READ(5,2) (ASW(K),K=1,NSW)
READ(5,2) (FRSW(K),K=1,NSW)
READ(5,2) (FIDSW(K),K=1,NSW)
READ(5,2) RHO, SUBM,TWX,TIY,CDASX,AMC,AFAC,TMIN
READ(5,2) TINV1,DT1,TOTT,DT2
READ(5,3) (FLC(K),K=1,NCAB)
READ(5,2) (DCI(K),K=1,NCAB)
READ(5,2) (CDN(K),K=1,NCAB)
READ(5,2) (CDT(K),K=1,NCAB)
READ(5,2) (WC(K),K=1,NCAB)
READ(5,4) (CM(K),K=1,NCAB)
READ(5,3) (TREF(K),K=1,NCAB)
READ(5,5) (C1(K),K=1,NCAB)
READ(5,2) (C2(K),K=1,NCAB)
READ(5,2) (CINT(K),K=1,NCAB)
READ(5,2) (WBD(K),K=1,NCAB)
READ(5,2) (CDABX(K),K=1,NCAB)
READ(5,2) (CDABY(K),K=1,NCAB)
READ(5,2) (XMBV(K),K=1,NCAB)
READ(5,2) (YMBV(K),K=1,NCAB)
READ(5,3) (YY(I),I=1,NCUR)
READ(5,3) (CCK(I),I=1,NCUR)
READ(5,2) (PHID(I),I=1,NCAB)
READ(5,3) (TENI(I),I=1,NCAB)
READ(5,2) (XPI(I),I=1,NCAB)
READ(5,2) (YPI(I),I=1,NCAB)

1000 CONTINUE
```

The corresponding FORMAT statements are:

```
1   FORMAT (24I3)
2   FORMAT (8F10.4)
3   FORMAT (8F10.2)
4   FORMAT (8F10.6)
5   FORMAT (8F10.0)
```

subroutine BUOY

```
READ (5,1) CDASY,WAS,RWY,RTX,RTY,YCG,BIN
READ (5,1) XSI,ZETI,SYDI,XPSI,ZTPI,SYPDI
```

The corresponding FORMAT statement is:

```
1  FORMAT (8F10.4)
```

DEFINITION OF INPUT VARIABLES FOR PROGRAM CABUOY

MAIN Program

NCASES — Number of cases, NCASES ≥ 1

NSM[1] — Number of surface motion components, $1 \leq$ NSM ≤ 20

NSW[2] — Number of surface wave components, $1 \leq$ NSW ≤ 20

NCAB — Number of cable segments, $2 \leq$ NCAB ≤ 50

NCUR — Number of current profile points, $2 \leq$ NCUR ≤ 10

FSM(K)[1]

AXSM(K)[1]

$$x_{SM} = \sum_{k=1}^{NSM} AXSM(K)*\cos(-2\pi*FSM(K)*t + FIDSM(K)*\pi/180.)$$

AYSM(K)[1]

FIDSM(K)[1]

$$y_{SM} = \sum_{k=1}^{NSM} - AYSM(K)*\sin(-2\pi*FSM(K)*t + FIDSM(K)*\pi/180.)$$

ASW(K)[2]

FRSW(K)[2]

$$x_{SW} = \sum_{k=1}^{NSW} ASW(K)*\cos(-2\pi*FRSW(K)*t + FIDSW(K)*\pi/180.)$$

FIDSW(K)[2]

$$y_{SW} = \sum_{k=1}^{NSW} -ASW(K)*\sin(-2\pi*FRSW(K)*t + FIDSW(K)*\pi/180.)$$

RHO — Fluid density in slugs/feet^3

SUBM[3] — Submergence of top point of cable below free surface in feet

TWX[3] — Horizontal force acting at top of cable in pounds

TWY — Vertical component of tension at top of cable in pounds

CDASX[3] — Drag area of surface buoy perpendicular to the x-axis in feet^2

AMC — Added mass coefficient of cable; AMC = 1.0 for round cable

AFAC	Cross-sectional area of cable = AFAC* $\pi d^2/4$; AFAC=1.0 for round cable
TMIN	Minimum algebraic tension which can be supported by cable
TINV1	Initial time interval for dynamic calculations in seconds
DT1	Time step for which print out is desired for $0 \le t \le$ TINV1 in seconds
TOTT	Total time for which dynamic calculations are desired in seconds
DT2	Time step for which print out is desired for TINV1 $< t \le$ TOTT in seconds
FLC(K)	Length of Kth cable segment in feet
DCI(K)	Diameter of Kth cable segment in inches
CDN(K)	Normal drag coefficient of Kth cable segment
CDT(K)	Tangential drag coefficient of Kth cable segment
WC(K)	Weight in fluid of Kth cable segment at the reference cable tension in pounds/foot
CM(K)	Mass of Kth cable segment at the reference cable tension in slugs/foot
TREF(K)	Reference tension of Kth cable segment in pounds
C1(K)[4], C2(K) CINT(K)	Tension = TREF(K) + C1(K)* $\varepsilon^{C2(K)}$ + CINT(K)* $\dot{\varepsilon}$; for linearly elastic material, C1(K) = AE and C2(K) = 1
WBD(K)	Weight in fluid of Kth body in pounds
CDABX(K)[5], CDABY(K)[5]	Drag area of Kth body for flow in (x,y) directions in ft^2
XMBV(K)[5], YMBV(K)[5]	Virtual mass (mass + added mass) of Kth body in (x,y) directions in slugs
YY(I)	Value of y in feet
CCK(I)	Value of current in knots at y = YY(I)
PHID(I)[6]	Initial value of ϕ of Ith cable segment in degrees
TENI(I)[6]	Initial value of tension of Ith cable segment in pounds
XPI(I)	Initial value of $\dot{x}$ of Ith node in feet/second

YPI(I) Initial value of $\dot{y}$ of Ith node in feet/second

Subroutine BUOY

CDASY Drag area for y-direction in feet^2

WAS Weight in air in pounds

RWY Vertical distance of wind loading center of pressure from buoy center of gravity YCG

RTX,RTY (x,y) distance of cable attachment point from YCG

YCG Submergence of center of gravity below the free surface under the action of its own weight in air WAS and the vertical component of the steady-state tension (-TIY)

BIN Moment of inertia in air about YCG in slug feet^2

XSI, ZETI, SYDI[7] Initial values of (x,ζ,ψ) in (feet, feet, degrees), where ζ is the vertical displacement of the center of gravity from its equilibrium value YCG

XPSI, ZTPI, SYPD1 Initial values of $(\dot{x},\dot{\zeta},\dot{\psi})$ in (feet/second, feet/second, degrees/second)

Footnotes

[1]For 1000. ≤ FSM(1) <2000., the program makes the prescribed surface motion components equal to the surface wave components by setting

AXSM(K) = AYSM(K) = ASW(K), FSM(K) = FRSW(K), and FIDSM(K) = FIDSW(K) for

K = 1 to K = NSM. Thus, NSM should be read in equal to NSW.

For 2000.≤ FSM (1) <3000., the program accepts input data for a spar buoy and considers AXSM(K) to be the cross-sectional area of the buoy in feet^2 at depth AYSM(K) feet below the free surface. AYSM(1) = 0. and AYSM(NSM) = total draft under the combined action of buoy weight in air and the vertical component of the steady-state tension. NSM should be an odd number. The input values for FIDSM(K) may take on any values such as, say, 0.

For FSM(1) $\geq$ 3000., the program accepts input data for a spheroidal buoy and considers AXSM(1) to be the radius of the buoy cross-section at the free surface and AYSM(1) to be the total draft. The rest of the input values of AXSM(K) and AYSM(K) as well as all of the FIDSM(K) may take on any values such as, say, 0.

[2]For ASW(1) >1000., the program computes the amplitudes of the NSW surface wave components by using the Pierson-Moskowitz sea spectrum. In these cases, the program considers the significant wave height in feet to be (ASW(1) - 1000.) and FRSW(1) and FRSW(2) to respectively be the lower and upper frequencies of the spectrum in cps. The program internally generates the phases of the wave components by considering them to be uniformly separated by 360/NSW degrees. Thus, the input values for the FIDSW(K) may be arbitrary such as, say, 0.

[3]For the case of a surface buoy (FSM(1) $\geq$ 2000.), the program calculates the drag acting on the surface buoy due to the ocean current by taking the value of the ocean current SUBM feet below the free surface. Thus, 0 $\leq$ SUBM $\leq$ total draft.

The total horizontal force at the top point of the cable TIX = TWX +(1/2)ρ* CDASX* CCF (SUBM)* ABS (CCF (SUBM)). In cases where there is no surface buoy (i.e., prescribed surface motion), TWX or CDASX may be set equal to zero. For cases of a surface buoy, TWX represents the wind loading on the buoy in pounds.

[4]For free-floating and towing cables where the last (K=NCAB) cable connecting the lower weight to the ocean bottom is fictitious, read in a value for C1(NCAB) between 0.01 and 0.1. Also, read DCI(NCAB) = CDN(NCAB) = CDT(NCAB) = WC(NCAB) = CM(NCAB) = CINT(NCAB) = 0. FLC(NCAB) and C2(NCAB) should be read in as an arbitrary nonzero values such as, say, 200 and 1, respectively.

[5]If CDABX(K) is negative, the program considers the body to be a circular disk with plane perpendicular to the x-axis and calculates drag and added mass forces by using the formulation given in Report NADC-AE-7120. In these cases, CDABX(K) is the negative of the actual drag area and XMBV(K) is the mass (not the virtual mass) of the disk. In these cases, CDABY(K) and YMBV(K)

should be positive and retain the definitions given previously. Similar remarks apply if CDABY(K) is read in as a negative number with the exception that the plane of the disk is now perpendicular to the y-axis.

[6]For $|\text{PHID}(1)| \geq 360.$, the program takes the initial values of the angle and tension of each cable segment to correspond to their respective steady-state values at the midpoint of each segment. These steady-state values have been previously calculated by the program. This approach will minimize transient dynamic effects. In these cases, input values for the remaining PHID(K) as well as all of the TENI(K) may be arbitrary such as, say, 0.

[7]For SYDI $\geq$ 360., the program sets the initial value for buoy inclination ψ equal to the steady-state value of ψ, which has been previously calculated by the program. This will tend to minimize transient dynamic motions of the surface buoy.

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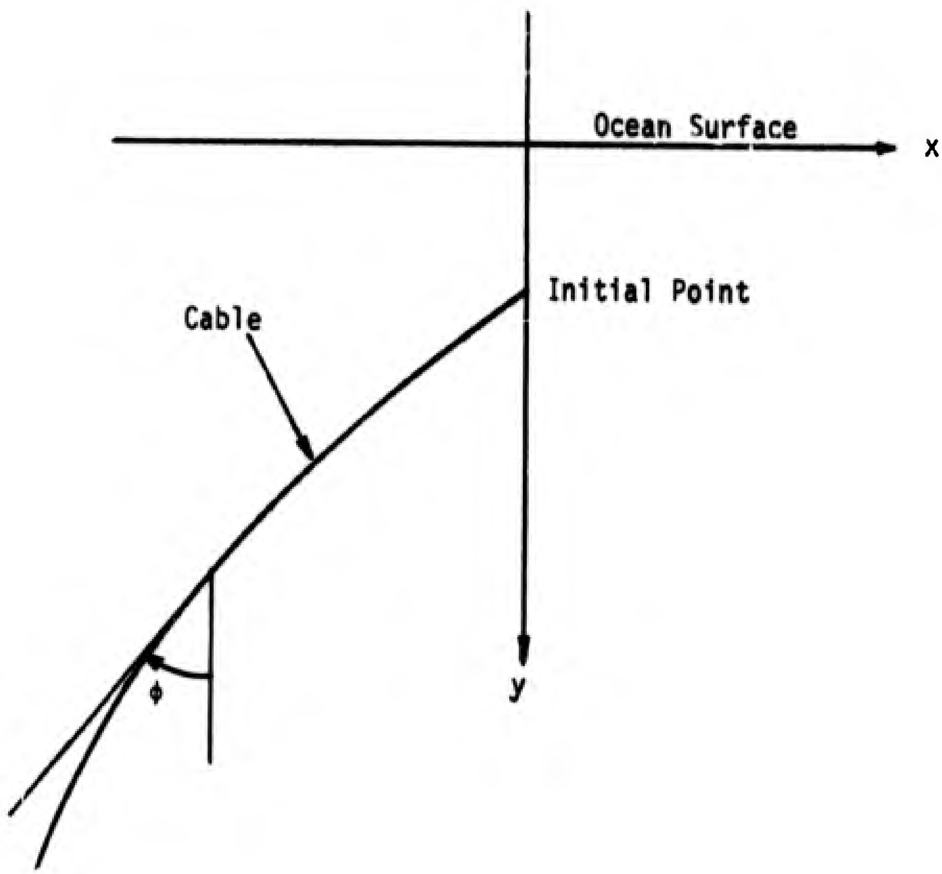

Figure 1 - Definition of Coordinate System