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NATFREQ USERS MANUAL – A FORTRAN IV PROGRAM FOR COMPUTING NATURAL FREQUENCIES, MODE SHAPES, AND DRAG COEFFICIENTS FOR TAUT STRUMMING CABLES WITH ATTACHED MASSES AND SPRING-MASS COMBINATIONS

June 1984

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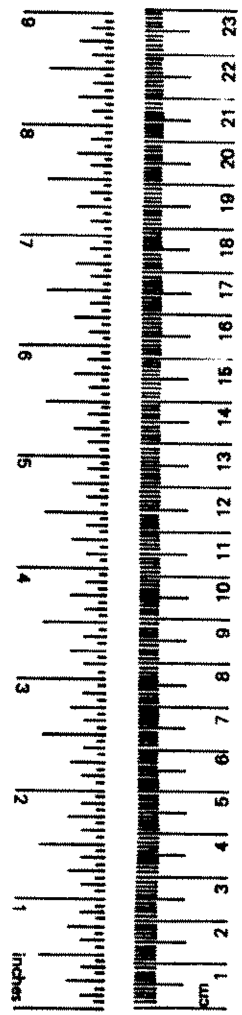
N62583/83 M R084

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

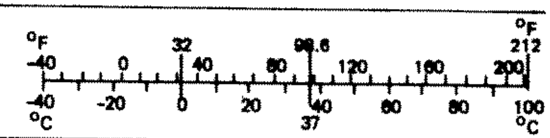
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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This manual describes a computer program that has been developed to calculate natural frequencies and mode shapes of taut cables with attached masses and spring-mass combinations. The equations of motion are solved by an iterative technique allowing accurate calculation even for extremely high mode numbers. The approach has the advantages that it is fast, accurate, and can easily accommodate a variety of system configurations including bodies

attached to the cable.

This document covers the theory used in the development of the code. Line-by-line descriptions of both the input and output data are given, and several examples illustrating the use of the program are included. Some of the difficulties that may be encountered when running large, complex problems are discussed and possible solutions proposed.

The structure of the program is described in moderate detail. The program is written in a style which makes additions or modifications easy to implement.

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1. INTRODUCTION

Many ocean systems employ cables either for structural support and anchoring or as active system components. Static and dynamic modeling of the interaction of a cable structure with the sea requires calculation of the loads due to cable drag. Strumming (vortex induced vibration) of the cables increases cable drag and also causes dynamic stress and water pressure variations. Several methods have been developed to predict the amplification of drag due to strumming and other dynamic effects. In general, these methods require a knowledge of the natural frequency and mode shape of the cable segment under consideration. Previously, matrix methods have been used to determine cable natural frequencies and mode shapes, but these have been found to be costly and subject to inaccuracy and possible lack of convergence for complex cable systems.

This manual describes a computer program called NATFREQ that has been developed to calculate natural frequencies and mode shapes of taut cables, with attached masses and spring-mass combinations. The equations of motion are solved by an iterative technique allowing accurate calculation even for extremely high mode numbers. The approach has the advantages that it is fast, accurate, and it can easily accommodate a variety of system configurations including bodies attached to the cable.

As an example of the type of cable system that may be analysed using NATFREQ, Figure 1.1 shows the response of a 15400 foot long cable with 380 attached flotation and instrument masses. The cable is subjected to a flow velocity of 0.30 knots which excites the mode number 151 of the cable system. The complex nature of the response is clearly beyond the range of intuition.

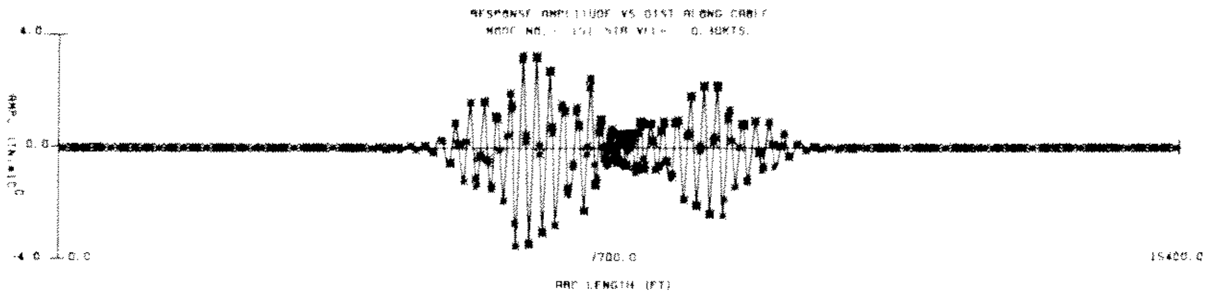


Figure 1.1. High Mode Number for a Real Cable System

The program NATFREQ finds the natural frequencies and mode shapes of the cable system. Then, using a wake-oscillator theory of vortex shedding adapted to internally elastic systems, [1], the amplitude of response in a particular mode is calculated. The flow velocity required to excite this mode is computed from the natural frequency using Strouhal's relationship. The drag amplification due to out-of-plane vibrations is calculated from an empirical model proposed by Skop, Ramberg, and Griffin [5].

Since the mode shape calculation has a significant influence on the drag calculation, the mode shape determination scheme has been verified by comparison to experimental data. An experiment was performed to measure the natural frequencies and mode shapes of a taut cable with several attached masses, and a comparison made with the predicted results [4]. Good agreement was found in this comparison.

1.1 Structure of this Document

The theory used in the program NATFREQ is described in Chapter 2. In sections 2.1 and 2.2, the algorithm for calculating the natural frequencies and mode shapes is developed and described. The calculation of the strumming amplitude is outlined in section 2.3, and the implementation of the program for non-uniform flow situations is discussed in section 2.4. Section 2.5 discusses the drag amplification due to strumming of the cable.

Chapter 3 describes the structure of the program. A short description of each subroutine is given, and a diagram indicating subprogram organization is included.

A detailed description of the input file(s) required to run the program is given in Chapter 4. A brief overview of the output and plotting options is followed by a line-by-line description of the required input sequence.

Chapter 5 contains the output and plotting option descriptions, and gives a line-by-line description of the output files.

In NATFREQ, a number of options have been included to improve the stability, convergence and accuracy of the algorithm. Chapter 6 describes these options, and outlines the limitations most likely to be encountered when using the program.

Finally, a number of examples are given in Chapter 7. These examples may be used as a supplement to Chapters 4 and 5 to clarify the options available to the user in particular applications.

Most users should be able to successfully run the program after reading Chapters 4, 5, and 7. Chapters 2, 3, and 6 may be needed only for clarification if difficulties arise.

To gain a complete understanding of NATFREQ and the theory involved, the user would need to read this entire manual including referenced documents. Unavoidably, some of the theory presented in Chapter 2 is complex and, for the sake of conciseness, rather abbreviated. This chapter may be beyond the scope of the background of some users, but it should be emphasized that a complete understanding of this chapter is not necessary to sucessfully implement the program.

1.2 Site Requirements and Programming Versatility

The program should run as delivered on any CDC system with a plotter that uses industry standard routines (as used by Calcomp). The language used was FORTRAN IV, and the program is written so as to facilitate adaption to other systems (e.g. PRIME, VAX, IBM, etc.). The principal changes to be made concern system specific routines such as calling the date and time, and specifying output file widths.

The plotting subroutines in the program make use of the basic industry standard plot routines, as used by Calcomp, Nicolet Zeta, etc. The program should not need any modification to run a plotter which uses these standard routines since no site specific plot packages are called.

Appendix V gives operator/user instructions for tailoring NATFREQ to a specific site.

2. THEORETICAL BACKGROUND

The natural frequencies and mode shapes of cable oscillation are obtained by an iterative substitution algorithm which finds the solution satisfying the imposed boundary conditions of the problem [4]. Then the amplitude of oscillation and effective drag coefficient are determined from empirical formulae.

2.1 Cable Dynamics

The system considered is shown in Figure 2.1. It consists of n cable segments, n-1 attached rigid masses, and n-1 attached spring-mass combinations. The ith segment has an effective mass per unit length ρ_i and a tension T_i, which are assumed constant over the length ℓ_i of the segment. The mass attached to the end of the ith cable segment is M_i. The attached spring-mass system at the end of the ith segment is assumed to have a spring stiffness k_i and a mass m_i. Either or both of the attached masses M_i or m_i may be zero. <u>All masses and densities include any added fluid mass</u>.

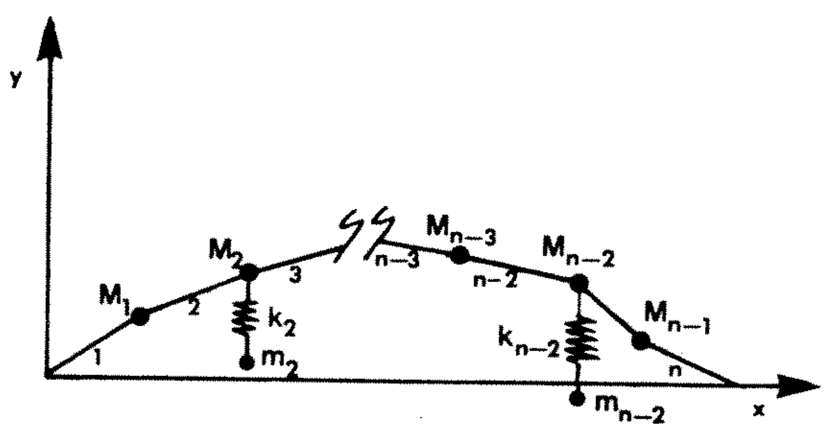


Figure 2.1. Typical cable segments

2.1.1 Equations of Motion

The equation of motion for the displacement y_i of the ith cable segment, assuming no bending rigidity, is (see Figure 2.2)

$$\rho_i \frac{\partial^2 y_i}{\partial t^2} = T_i \frac{\partial^2 y_i}{\partial x^2} \; ; \qquad i = 1,\ldots,n \tag{2-1}$$

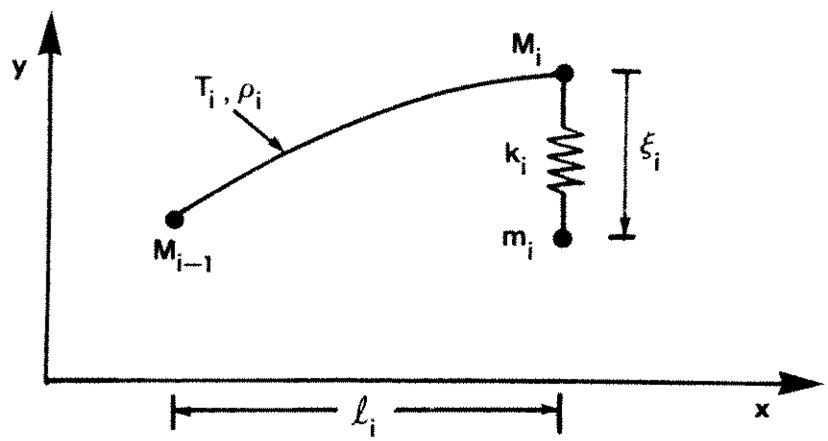


Figure 2.2. Displacement of the ith segment

The harmonic solution of this equation has the form

$$y_i(x,t) = Y_i(x)\, e^{j\omega t} \tag{2-2}$$

where $Y_i(x)$ gives the shape of deformation, and ω is the frequency of oscillation. Substituting Equation (2-2) into Equation (2-1) gives

$$Y_i(x) = A_i \sin\alpha_i\omega x + B_i \cos\alpha_i\omega x \; ; \qquad 0 \le x \le \ell_i \tag{2-3}$$

$$i = 1,\ldots,n$$

where

$$\alpha_i = (\rho_i/T_i)^{1/2} \tag{2-4}$$

In addition to satisfying the equation of motion, the deflection of each cable segment must satisfy certain additional conditions. These result from the geometric dynamic boundary conditions imposed on the ends of the entire cable assembly, the continuity of displacement at each attached mass, and the balance of forces at each attached mass and/or spring-mass combination.

2.1.2 Continuity of Displacement

The displacement must be continuous at each attached mass. Therefore

$$Y_{i+1}(0) = Y_i(\ell_i) \tag{2-5}$$

Substituting from Equation (2-3) yields

$$B_{i+1} = A_i \sin\alpha_i\omega\ell_i + B_i \cos\alpha_i\omega\ell_i \tag{2-6}$$

Equation (2-6) may be used to find B_{i+1} if A_i and B_i are known.

2.1.3 Force Balance

Figure 2.3 shows the forces acting at each attached mass/sprung mass location. The balance of forces at these points gives

$$T_{i+1} \left.\frac{\partial y_{i+1}}{\partial x}\right|_{x=0} - T_i \left.\frac{\partial y_i}{\partial x}\right|_{x=\ell_i} = M_i \left.\frac{\partial^2 y_{i+1}}{\partial t^2}\right|_{x=0} + k_i \left.\xi_i(t)\right|_{x=\ell_i}$$

.... (2-7)

where ξ_i is the relative displacement of the ith sprung mass, measured from the equilibrium position as shown in Figure 2.2. Static equilibrium forces are neglected for the dynamic case.

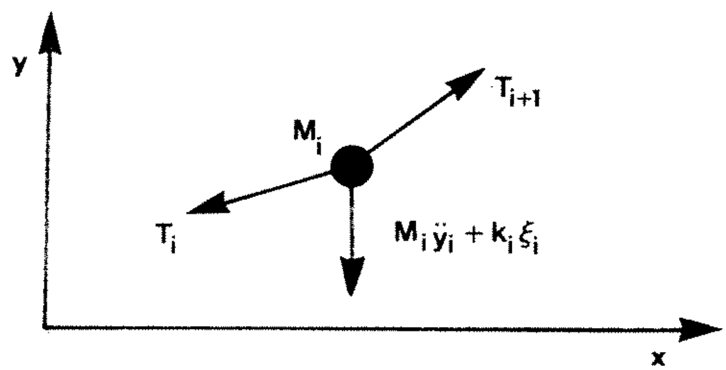


Figure 2.3. Force balance (neglecting static equilibrium forces)

Substituting from Equation (2-3) yields

$$T_{i+1}\ \alpha_{i+1}\ A_{i+1} - T_i\ (\alpha_i\ A_i\ \cos\alpha_i\omega\ell_i - \alpha_i\ B_i\ \sin\alpha_i\omega\ell_i)$$

$$= -M_i\ \omega\ B_{i+1} - \frac{k_i\ \omega}{\omega_i^2 - \omega^2}\ B_{i+1}\ ; \qquad i = 1,\ldots,n \qquad (2\text{-}8)$$

Solving Equation (2-8) for A_{i+1} gives

$$A_{i+1} = \frac{\alpha_i\ T_i}{\alpha_{i+1}\ T_{i+1}} \left[A_i\ \cos\alpha_i\omega\ell_i - B_i\ \sin\alpha_i\omega\ell_i\right]$$

$$+ \frac{M_i\omega}{\alpha_{i+1}T_{i+1}}\left[-1 + \frac{k_i/M_i}{(\omega^2 - k_i/m_i)}\right] B_{i+1} \qquad (2\text{-}9)$$

Equations (2-6) and (2-9) may be used to find A_{i+1} if A_i and B_i are known.

2.1.4 Boundary Conditions

At the left hand end of the cable assembly, the displacement is assumed to be zero. Thus,

$$Y_1(0) = 0 \qquad (2\text{-}10)$$

Substituting from Equation (2-3) thus implies that

$$B_1 = 0 \qquad (2\text{-}11)$$

Since the magnitude of the deflected shape of the cable (mode shape) is, at this point arbitrary, let

$$A_1 = 1 \qquad (2\text{-}12)$$

With conditions (2-11) and (2-12) on A_1 and B_1, and Equations (2-6) and (2-9) for A_{i+1} and B_{i+1}, all subsequent A's and B's may be determined, provided ω, the natural frequency is known.

The system must satisfy one additional boundary condition at the right hand end of the assembly. Two possible options are considered herein; a fixed end condition and a free end condition.

Fixed End

For a fixed end condition, the displacement at the right hand end of the last segment is zero. This gives

$$Y_n(\ell_n) = 0 = Y_{n+1}(0) \tag{2-13}$$

Equation (2-13) in turn implies that

$$B_{n+1} = 0 \tag{2-14a}$$

Free End

For a free end condition, the total force at the right hand end of the last cable segment must equal zero. This implies that the first term in Equation (2-7) must vanish, so that there is no force in the (n+1)th "imaginary" segment. Using Equation (2-3), this gives the right hand boundary condition as

$$A_{n+1} = 0 \tag{2-14b}$$

The values of ω which give solutions satisfying condition (2-14a) or (2-14b) are the natural frequencies of the system.

2.2 Solution Algorithm for Mode Shapes and Frequencies

If ω is increased from zero and the corresponding values of B_{n+1} or A_{n+1} calculated, the result will be shown as in Figure 2.4. Each point, $\omega = \omega_k$, for which $B_{n+1} = 0$ or $A_{n+1} = 0$ represents a valid solution of the corresponding free oscillation problem. The ω_k so obtained are the natural frequencies of the system. There are an infinite number of such frequencies.

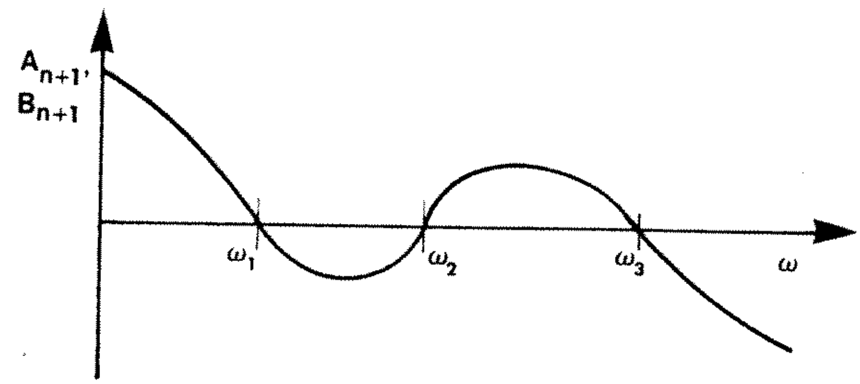


Figure 2.4. System natural frequencies

The mode shape of response of the ith segment associated with each natural frequency ω_k will be denoted by $Y_i^{(k)}(x)$. Then,

$$Y_i^{(k)}(x) = A_i^{(k)} \sin\alpha_i\omega_k x + B_i^{(k)} \cos\alpha_i\omega_k x \qquad (2\text{-}15)$$

The wavelength of the mode shape of a particular cable segment is given by

$$L_i^{(k)} = \frac{2\pi}{\alpha_i\omega_k}. \qquad (2\text{-}16)$$

The mode shape of the entire cable system will be such that the number of internal zero crossings (nodes) is equal to k-1. The mode number of a particular mode shape may therefore be obtained by counting the number of internal zeros associated with the functions $Y_i^{(k)}$; i = 1,...,n. The solution process for the mode shapes and frequencies may be summarized as follows:

1. Assume a value for ω_k.

2. Let $B_1 = 0$, $A_1 = 1$.

3. Solve for B_2, A_2; B_3, A_3; ...; B_n, A_n; B_{n+1}.

4. Check for $B_{n+1} = 0$ (fixed end) or $A_{n+1} = 0$ (free end). If end condition is not satisfied, compare with previous value and estimate a new trial value for ω.

5. Go to step 2 and repeat until either the end condition is less than some prescribed accuracy or the change in ω_k is less than some prescribed value.

6. Determine the mode number by counting the number of internal zeros of the mode shape $Y_i^{(k)}(x)$; $i = 1,\ldots,n$.

2.3 Strumming Amplitude - Nonuniform Cable

It will be assumed with References [1,3] that the displacement, y, of the cable including attached masses may be described by a differential equation of motion of the form

$$\rho(x)\frac{\partial^2 y}{\partial t^2} + \gamma(x)\frac{\partial y}{\partial t} - T(x)\frac{\partial^2 y}{\partial x^2} = \alpha_4 \; g(x)\left[\frac{\partial z}{\partial t} - \frac{\partial y}{\partial t}\right] \qquad (2\text{-}17)$$

where $\rho(x)$ is the mass per unit length of the cable system, α_4 is a flow model parameter, z is a hidden flow variable, and g(x) is a parameter which specifies the nature of the fluid structure coupling. The function g(x) is defined as follows :

$g(x) = 1$; for those portions of the cable where "locked-in" vortex shedding is taking place.

$= 0$; for those portions of the cable where "locked-in" vortex shedding is not taking place. (2-18)

The damping function or operator $\gamma(x)$ must account for the effects of three types of damping :

1. the internal cable damping (assumed viscous),
2. the fluid drag damping of the attached masses, and
3. the fluid drag damping of inactive cable segments which are not being excited by vortex shedding.

$\gamma(x)$ may be represented as

$$\gamma(x) = \hat{\gamma}(x) + \sum_{i=1}^{n-1} C_{m_i}\delta(x-x_i) + [1-g(x)]C_c(x) \qquad (2\text{-}19)$$

where

$\hat{\gamma}(x)$ = a function/parameter accounting for internal viscous cable damping,

C_{m_i} = the effective viscous damping coefficient for fluid drag on the ith attached mass,

$C_c(x)$ = the effective viscous damping coefficient for fluid drag on the cable, and

$\delta(x-x_i)$ = a delta function at the location of the ith attached mass.

For harmonic oscillation, an effective viscous damping coefficient may be defined for a velocity-squared pressure drag using harmonic balance [2]. For the attached masses, this will yield

$$C_{m_i} = \frac{8}{3\pi} \left[\frac{C_{Dm_i} \rho A_i}{2} \right] \left| \frac{\partial y}{\partial t}(x_i) \right|_{ampl} \qquad (2\text{-}20)$$

where C_{Dm_i} and A_i are the drag coefficient and area respectively of the ith attached mass and ρ is the fluid density. The symbol $|.|_{ampl}$ is used to denote the amplitude of a harmonic function of time.

The effective viscous damping coefficient will vary for each cable segment. Let C_{c_i} denote the effective damping coefficient of the ith segment. Then, from harmonic balance,

$$C_{c_i}(x) = \frac{8}{3\pi} \left[\frac{C_{Dc_i} \rho D_i}{2} \right] \left| \frac{\partial y}{\partial t}(x) \right|_{ampl} \qquad (2\text{-}21)$$

where C_{Dc_i} and D_i are the drag coefficient and diameter respectively of the ith cable segment.

The equation for z, the hidden flow variable, assuming no spanwise coupling within the flow is given in Reference [1], Equation 6 as

$$\frac{\partial^2 z}{\partial t^2} - \left[\frac{(a_1 - a_4)}{a_0} \frac{U}{D} - \frac{a_2}{a_0} \frac{1}{UD} \left(\frac{\partial z}{\partial t}\right)^2 \right] \left(\frac{\partial z}{\partial t}\right) + \omega_s^2 z = \frac{a_4}{a_0} \frac{U}{D} \frac{\partial y}{\partial t}(x,t) \qquad (2\text{-}22)$$

The a_i; (i = 0, 1, 2, 4) are dimensionless model parameters defined in Reference [3]. U is the cross-flow velocity, D the cable diameter, and ω_s the vortex shedding frequency given by

$$\omega_s = 2\pi S \frac{U}{D} \tag{2-23}$$

where S is the Strouhal Number.

In order to generate a solution of Equations (2-17) and (2-21), let y and z be expanded in terms of the mode shapes of the cable as

$$y(x,t) = \sum_{j=1}^{\infty} Y^{(j)}(x)\bar{y}_j(t)$$

$$z(x,t) = \sum_{j=1}^{\infty} Y^{(j)}(x)\bar{z}_j(t) \tag{2-24}$$

where $Y^{(j)}(x)$ is the mode shape of oscillation in the jth mode given by Equation (2-15), and $y_j(t)$ and $z_j(t)$ are time dependent modal coefficients.

After substituting Equations (2-24) into Equation (2-22), the resulting equation may be multiplied by $Y^{(k)}(x)$ and integrated over the length of the cable. Due to the segmented nature of the cable, the integration must be performed carefully. For example,

$$\int_0^{\ell} \rho(x)f(x)dx = \sum_{i=1}^{n} \int_0^{\ell_i} \rho_i(x)f(x)dx + \sum_{i=1}^{n-1} M_i f(x)\delta(x-x_i) \tag{2-25}$$

where f(x) is some function of x, and $\delta(x-x_i)$ has the same meaning as in Equation (2-19).

The resulting equation may be written as

$$\ddot{\bar{z}}_k(t) - \left[\frac{a_1-a_4}{a_0}\frac{U}{D} - \frac{a_2}{a_0}\frac{1}{UD}\hat{I}^{(k)}\dot{\bar{z}}_k^2(t)\right]\dot{\bar{z}}_k(t) + \omega_s^2\bar{z}_k(t) = \frac{a_4}{a_0}\frac{U}{D}\dot{\bar{y}}_k(t)$$

.... (2-26)

where

$$\hat{I}^{(k)} = \frac{\sum_{i=1}^{n}\int_0^{\ell_i}\rho_i(x)[Y_i^{(k)}(x)]^4dx + \sum_{i=1}^{n-1}M_i[Y_{i+1}^{(k)}(0)]^4}{\sum_{i=1}^{n}\int_0^{\ell_i}\rho_i(x)[Y_i^{(k)}(x)]^2dx + \sum_{i=1}^{n-1}M_i[Y_{i+1}^{(k)}(0)]^2} \qquad (2\text{-}27)$$

Equation (2-26) is in precisely the same form as Equation 17 in Reference [1].

In a similiar fashion, substitution of Equations (2-24) into Equation (2-17) yields

$$\ddot{\bar{y}}_k(t) + 2\zeta_k^T\omega_k\dot{\bar{y}}_k(t) + \omega_k^2\bar{y}_k(t) = \frac{\alpha_4}{\hat{\mu}_k}\bar{z}_k(t) \qquad (2\text{-}28)$$

where

$$\zeta_k^T = \zeta_k^s + \frac{\alpha_4}{\hat{\mu}_k} \qquad (2\text{-}29)$$

$$\zeta_k^s = \zeta_k^0 + \frac{1}{2\omega_k\eta_k}\left[\sum_{i=1}^{n}\int_0^{\ell_i}[Y_i^{(k)}(x)]^2[1-g(x)]C_{c_i}(x)dx + \sum_{i=1}^{n-1}C_{m_i}[Y_{i+1}^{(k)}(0)]^2\right] \qquad (2\text{-}30)$$

$$\eta_k = \sum_{i=1}^{n} \rho_i \int_0^{\ell_i} [Y_i^{(k)}(x)]^2 dx + \sum_{i=1}^{n-1} M_i [Y_{i+1}^{(k)}(0)]^2 \tag{2-31}$$

$$\hat{\mu}_k = \frac{\eta_k}{\sum_{i=1}^{n} \int_0^{\ell_i} [Y_i^{(k)}(x)]^2 g(x) dx} \tag{2-32}$$

ζ_0^k is the internal cable damping expressed as a fraction of critical damping, while ζ_k^s is the effective fraction of critical damping for the system including cable and attached mass fluid drag. $\hat{\mu}_k$ is a mass parameter.

Equations (2-26) and (2-28) are of exactly the same form as Equations 17 and 12, respectively in Reference [1], with appropriate modifications to the coefficients. Hence, the analysis in [1] may be followed directly.

Making use of the empirical relationships for the amplitude of response developed for circular cylinders [1], and letting the vortex shedding frequency, ω_s be equal to the system natural frequency, ω_k, the expression for the amplitude of response of the ith cable segment may be shown to be

$$y_i(x) = y_i^{(k)}(x) = P^{(k)} [\hat{I}^{(k)}]^{-1/2} d_s Y_i^{(k)}(x) \; ; \; i = 1,\ldots,n \tag{2-33}$$

where $P^{(k)}$ is an amplification factor, $\hat{I}^{(k)}$ is a mode shape factor, and d_s is the diameter of those cable segments actually shedding vortices.

The factor $P^{(k)}$ may be expressed empirically as ([1])

$$P^{(k)} = \frac{1}{1 + 9.60(\mu_r^{(k)}\zeta_k^s)^{1.8}} \qquad (2\text{-}34)$$

where $\mu_r^{(k)}$ is an effective mass ratio parameter. For the present case, it may be shown that

$$\mu_r^{(k)} = \frac{1}{\pi\rho d_s^2/4}\hat{\mu}_k \qquad (2\text{-}35)$$

Using the equations for the equivalent viscous damping coefficients for the system, Equation (2-30) may be expressed in the form

$$\zeta_k^s = \zeta_k^0 + P^{(k)}\Phi^{(k)} \qquad (2\text{-}36)$$

where

$$\Phi^{(k)} = \frac{4d_s}{3\pi} \frac{\sum_{i=1}^{n-1}\left[\frac{C_{Dm_i}\rho A_i}{2}\right]\left|Y_{i+1}^{(k)}(0)\right|^3 + \sum_{i=1}^{n}\frac{C_{Dc_i}\rho D_i}{2}\int_0^{\ell_i}\left|Y_i^{(k)}(x)\mathrm{right}\right|^3[1-g(x)]dx}{\eta_k^{1/2}\left[\sum_{i=1}^{n}\rho_i\int_0^{\ell_i}[Y_i^{(k)}(x)]^4dx + \sum_{i=1}^{n-1}M_i[Y_{i+1}^{(k)}(0)]^4\right]^{1/2}}$$

.... (2-37)

Due to the presence of the amplitude of oscillation implicitly in the equation for damping fraction, ζ_k^s must be solved for numerically using a Newton-Raphson technique. This is outlined in Appendix I.

Many of the integrals involved in the preceding derivation may be simplified by substitution of Equation (2-15) for the mode shape of the ith cable segment. Some of these simplifications are given in Appendix II.

Equations (2-33) - (2-36) represent the complete solution for the strumming amplitude of response. Equations (2-34) and (2-36) are first combined to solve numerically for the overall effective damping factor, ζ_k^s. Then, the results of Equations (2-27) and (2-34) are substituted into Equation (2-33) to calculate $y_i(x)$.

It should be noted at this point that if the system is uniform, with no attached masses, then the amplitude of response, as given by Equation (2-33), will be a constant for all modes. The integrals appearing in all the terms in (2-33) may be shown to reduce to constants that are independent of mode number in this case.

2.4 Simulation of Nonuniform Flow

The equations developed for the case of a nonuniform cable system may, with very little modification, be applied to a nonuniform flow situation. This may be accomplished by specification of the coupling parameter, g(x), as follows :

1. For a given mode of the system, a shedding velocity profile is determined for the entire cable system according to the expression

$$v_s(x) = \frac{\omega_k \, d(x)}{2\pi S} \qquad (2\text{-}38)$$

where v_s is the shedding velocity, d(x) is the cable diameter as a function of position along the cable, and S is the Strouhal Number.

2. The shedding velocity profile is compared to the "input" velocity profile. For regions of the cable where the two profiles are within some specified range of each other, the flow is assumed to

be locked-in and g(x) is set equal to one. For all other regions of the cable, g(x) is set to zero. i.e.

$$g(x) = 1 \quad ; \quad \left| \frac{v_s(x) - v_I(x)}{v_I(x)} \right| \leq \varepsilon$$

$$= 0 \quad ; \quad \text{elsewhere.} \qquad (2\text{-}39)$$

Additional cable segments may be added as necessary to accurately define the boundaries of g(x) = 1.

3. Equations (2-33) - (2-36) are solved and the amplitude of oscillation determined.

4. The mode number is changed and steps 1 - 3 are repeated.

5. The modal amplitudes of response may be combined in any consistent manner such a s the square root of the sum of the squares method.

The nonuniform flow calculation has not yet been incorporated into the NATFREQ code.

2.5 Drag Amplification

The average drag coefficient, $C_{Dc_{ave}}$, for the entire cable system (excluding attached masses and assuming constant diameter within a segment) will be defined as

$$C_{Dc_{ave}} = \frac{\sum_{i=1}^{n} C_{Dc_i} \, d_i \, \ell_i}{\sum_{i=1}^{n} d_i \, \ell_i} \qquad (2\text{-}40)$$

where C_{Dc_i} is the drag coefficient, d_i the diameter, and ℓ_i the length, of the ith cable segment. The weighting area is simply the sum of the segment lengths multiplied by the segment diameters.

In a similar manner, the average drag coefficient for the attached masses is given by

$$CDA_{ave} = \frac{\sum_{i=1}^{n} CDA_i \; A_i}{\sum_{i=1}^{n} A_i} \tag{2-41}$$

where CDA_i is the coefficient of drag and A_i the effective projected area of the attached weight at the end of the ith segment.

The drag amplification due to strumming oscillation is assumed to be given by the theory presented by Skop, Griffin, and Ramberg [5]. For the cable only, this gives

$$\frac{C_{D_i}(x)}{C_{Dc_i}} = 1.0 + 1.16(2y_i(x)/d_i)^{0.65}; \quad i = 1,\ldots,n \tag{2-42}$$

where $C_{D_i}(x)$ is the effective drag coefficient of the ith cable segment in the flow direction, and C_{Dc_i} is the nominal drag coefficient of the cable at rest as defined earlier. The drag coefficient so modified for strumming effects is presented in the program as an average value for the segment, C_{D_i}, where

$$C_{D_i} = \frac{\int_0^{\ell_i} C_{D_i}(x)dx}{\ell_i} \tag{2-43}$$

The integral in Equation (2-43) may be evaluated analytically for portions of the cable system which are full cycles of a harmonic function, or by numerical integration.

Drag amplification on the attached weights is calculated in a similar way, using the effective diameter of the mass and the displacement at the mass location.

The new averages of drag coefficient for the cable and the attached weights are calculated using Equations (2-40) and (2-41), except the modified coefficients are used. An overall average drag increase is defined as follows, allowing for both the masses and the cable, once again weighted by projected area.

$$CDT_{ave} = \left\{ \frac{\left[\sum_{i=1}^{n} C_{Dc_i} d_i \ell_i + \sum_{i=1}^{n} CDA_i \; A_i\right]_{modified}}{\left[\sum_{i=1}^{n} C_{Dc_i} d_i \ell_i + \sum_{i=1}^{n} CDA_i \; A_i\right]_{original}} - 1 \right\} \times 100\% \qquad (2\text{-}44)$$

3. PROGRAM STRUCTURE

The NATFREQ program consists of a short main or driving program and a series of separate subroutines. The reasons for this organization are :

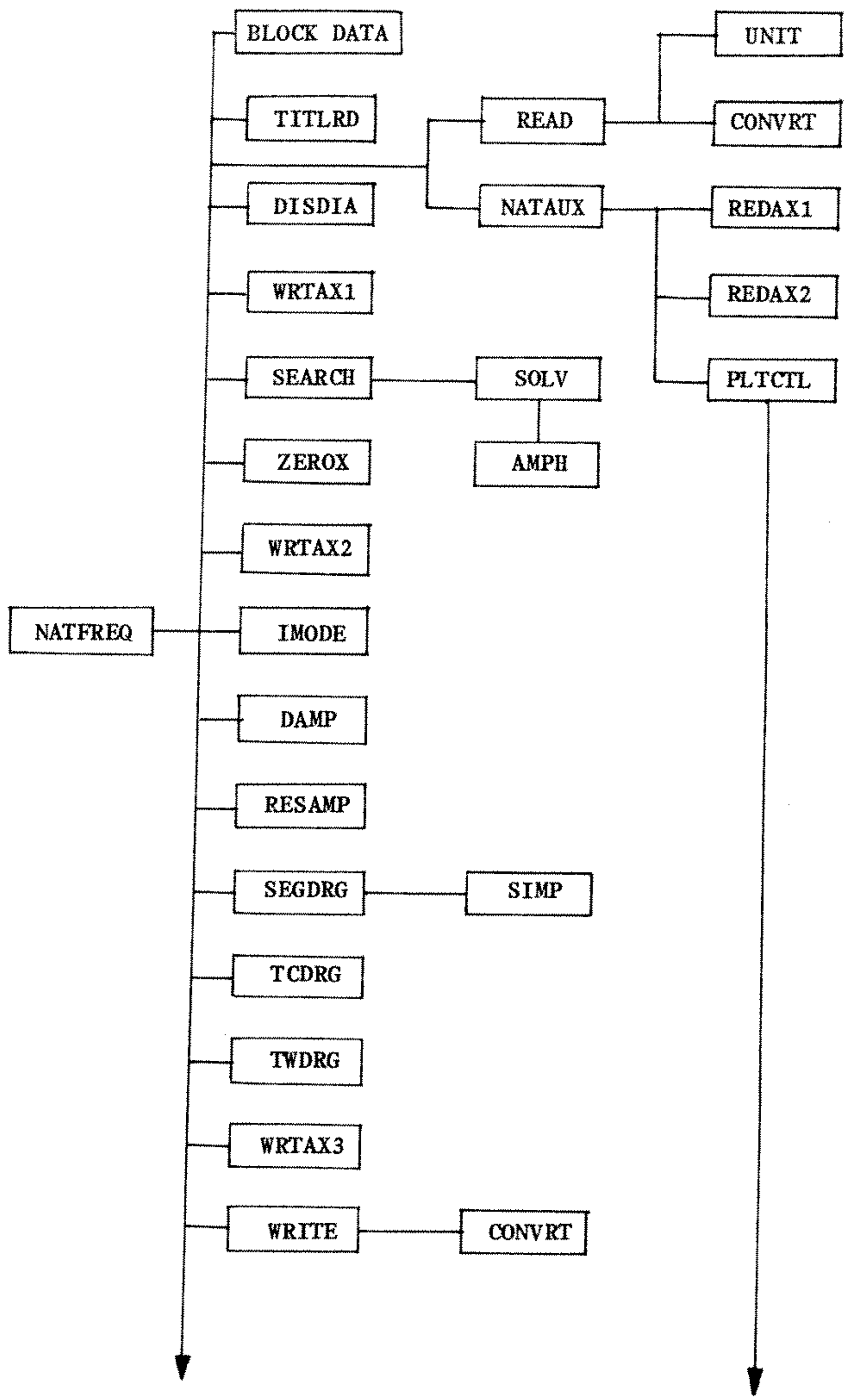
- debugging of the program and input data is more readily performed,
- alteration or upgrading of existing methods is more easily accomplished, and
- new options or routines are more easily added.

An overview of the structure of the program is given in Figure 3.1. A complete listing is given in Appendix VI.

A brief description of the separate program elements is given below.

3.1 Program NATFREQ

The driver program, NATFREQ, serves to coordinate the execution of all other program elements. Initially, TITLRD and READ are called to input the required data, then the first natural frequency and mode shape are found using SEARCH, AMPH, and ZEROX. IMODE, DAMP, RESAMP, SEGDRG and TOTDRG are sequentially called to calculate the cable response due to vortex shedding. Subroutine WRITE is then called to output the results, and, if plotting is desired, PLTCTL is utilized. The above steps are repeated for further modes in the specified range. Other subroutines may be called by NATFREQ depending on the options chosen.



NATFREQ
BLOCK DATA
TITLRD
READ
UNIT
CONVRT
NATAUX
REDAX1
REDAX2
PLTCTL
DISDIA
WRTAX1
SEARCH
SOLV
AMPH
ZEROX
WRTAX2
IMODE
DAMP
RESAMP
SEGDRG
SIMP
TCDRG
TWDRG
WRTAX3
WRITE
CONVRT

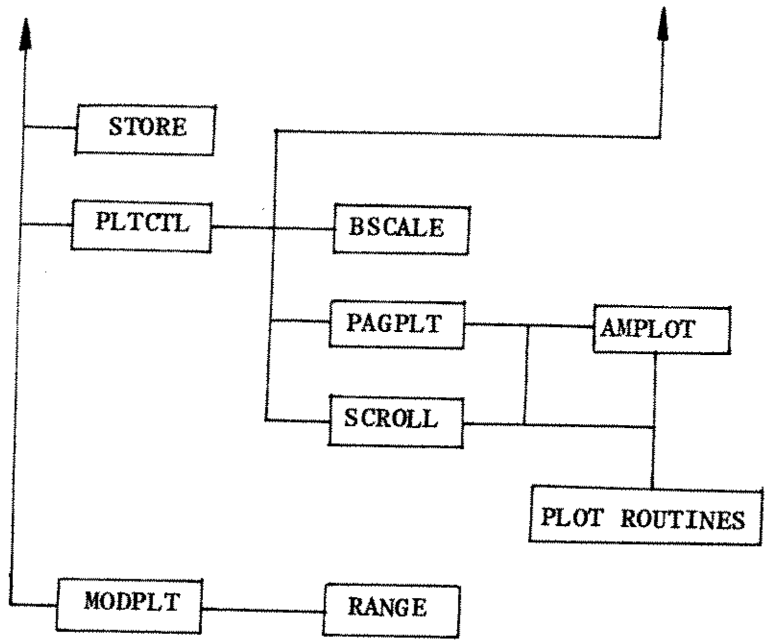


Figure 3.1. Program Structure

3.2 Subprogram BLOCK DATA

In BLOCK DATA, certain program constants are set. π and the Strouhal number (taken as 0.21) are defined, as well as the input and output device numbers. The presence of certain constants in this program element makes it easy to change these constants globally if desired.

3.3 Subroutine AMPH

Calculates the normalized amplitude and phase of the calculated mode shape. The maximum modal response in each segment and over the whole cable is also found in this routine.

3.4 Subroutine AMPLOT

Plots the scaled points if a plotting routine is called. Subroutines PAGPLT and SCROLL set up the axes and labelling, then each calls AMPLOT to plot the data.

3.5 Subroutine BSCALE

Evaluates the scale to which the output cable response is plotted.

3.6 Subroutine CONVRT

The natural frequencies are found in units of rad/sec. CONVRT converts these units to hertz, and effective cross-flow velocity (using the Strouhal relationship) in ft/sec, cm/sec, and knots for output purposes.

3.7 Subroutine DAMP

The effective damping ratio for the cable must be found in an iterative manner as outlined in Chapter 2. DAMP calculates this ratio using a standard Newton-Raphson technique (see Appendix I).

3.8 Subroutine DISDIA

The relationship between vortex shedding frequency and cross-flow velocity depends on the diameter of the shedding element (see Equation 2-22). DISDIA scans the input diameters, counting and storing the distinct values it encounters. These are used subsequently to evaluate the response when different sections of the cable are being excited at different cross-flow velocities.

3.9 Subroutine IMODE

IMODE calculates the mode shape factor, $\hat{I}^{(k)}$, (Eq 2-26) using the results of Appendix II. It also calculates the integrals appearing in the damping terms of Equation 2-36, which are used later in subroutine DAMP.

3.10 Subroutine MODPLT

Subroutine to control the plotting of the mode number vs. flow velocity plot, if this is desired. RANGE is called to perform the actual plotting of data (see also RANGE).

3.11 Subroutine NATAUX

As discussed more fully in Chapters 4 and 5, the program optionally generates "auxiliary data files" which may be used for post-processing applications. If a file of this type is used as input to the program, NATAUX controls the execution of the program in a similar way to NATFREQ if a "normal" data file was used. REDAX1 and REDAX2 are called to read the file, and the plotting routine requested is called.

3.12 Subroutine PAGPLT

PAGPLT is an alternative plotting routine. It minimizes labelling and produces smaller plots. The default plotted cable axis length is 10 inches. The plots are produced sideways on the page, and are arranged to fit three per standard 8.5 x 11 page. Plotter set-up is discussed more fully in Chapter 4.

3.13 Subroutine PLTCTL

If a plotting option is chosen, PLTCTL is called by the main program. A scale is established for the plotting routines using BSCALE, then control is transferred to PAGPLT or SCROLL to perform the actual plotting.

3.14 Subroutine RANGE

The Strouhal relationship (2-23) indicates that for a given flow velocity, the vortex shedding frequency depends on the diameter of the cable. For a cable with segments of several distinct diameters, one can deduce from the model that several modes may be excited by a very narrow range of flow velocities. If this occurs, the applicability of the model in that region may be in question. RANGE plots the mode number against flow velocity over the specified frequency range so behavior of this type may be detected. Example 1 in Chapter 7 illustrates this behavior and the use of a mode vs. velocity plot in greater detail.

3.15 Subroutine READ

For normal program operation, the input data enters the program through READ. General information (number of segments, boundary condition code, cable damping, fluid density) is entered first, followed by the cable parameters (diameters, segment lengths, drag coefficients, etc.). Automatic generation options are included to reduce the tedium of creating large input files. Frequency search data (lower limit, increment, etc.) is then entered. Finally, output and plotting codes and associated data are input. Most of the data is echoed as output in a convenient tabular manner to give a complete listing.

3.16 Subroutine REDAX1

Called by NATAUX to read the auxiliary data file. REDAX1 reads in the general problem data (no. of segments, cable segment lengths, etc.) in abbreviated form.

3.17 Subroutine REDAX2

Again, called by NATAUX to read the auxiliary data file. REDAX2 reads the generated modal data (phase, etc.) and the strumming amplitudes for plotting. Time is saved by reading only the specified range of segments needed for plotting.

3.18 Subroutine RESAMP

The nominal mode shape of the cable is scaled according to Equation 2-32 to give the strumming response amplitude due to vortex shedding.

3.19 Subroutine SCROLL

This is one of two plotting options available, producing a 8 inch ordinate axis and comprehensive labelling. It is best produced on continuous, or roll, paper as the cable distance axis (abscissa) may be input as any length (default is 20 inches). These plots are most useful when a detailed output is desired, as the plot size is generally large.

3.20 Subroutine SEARCH

Natural frequencies are found by the "shooting" technique described in Chapter 2. SEARCH controls this process and adjusts successive estimates to enable convergence to the next system frequency. Subroutine SOLV is called to calculate the $A_i^{(k)}$'s and $B_i^{(k)}$'s (Eq 2-15).

3.21 Subroutine SEGDRG

The drag on the strumming cable is increased by the out of plane vibration (Eq 2-39). This subroutine evaluates the modified drag coefficient on each segment by averaging the above equation over the length of the segment. SIMP is called to numerically integrate the equation.

3.22 Subroutine SIMP

Subroutine to numerically integrate the drag amplification expression over the segments by Simpson's rule.

3.23 Subroutine SOLV

SOLV calculates the $A_i^{(k)}$'s and $B_i^{(k)}$'s for the cable system at a particular frequency estimate as described in Chapter 2. Control is returned to SEARCH which updates or accepts the current estimate before returning to SOLV or back to the main program.

3.24 Subroutine STORE

This subroutine stores the mode number and Strouhal velocity data for plotting by RANGE if this option is requested. (See also RANGE, MODPLT).

3.25 Subroutine TCDRG

The average amplified drag over the whole cable is evaluated by averaging the individual segment drags from SEGDRG.

3.26 Subroutine TITLRD

All preliminary program information is controlled by TITLRD. This includes reading and writing the title, date, and time. Program "Notes on Output" are also written here, and adding extra ones is easily effected, if appropriate. Column headings for input data echo are then printed.

3.27 Subroutine TWDRG

The effective coefficient of drag on the attached masses is also increased by the out of plane vibration. TWDRG, in a similar manner to TCDRG, calculates this drag increase, then finds an overall average increase in drag coefficient for the whole cable, allowing for both cable segments and attached masses.

3.28 Subroutine UNIT

The input units for the frequency search algorithm, SEARCH, (hertz, ft/sec, cm/sec, knots) are converted to rad/sec for iteration. UNIT is essentially the inverse of CONVRT.

3.29 Subroutine WRITE

WRITE is used to output the results of the program (mass response amplitude, segment response amplitude, drag coefficients, etc.) in a tabular manner. Several options for output are available, as discussed

Chapters 4 and 5.

3.30 Subroutine WRTAX1

If the option to write an auxiliary data file is chosen, WRTAX1 is called to output the title and general segment information. As these files are considered to be useful for debugging problems where, for example, difficulty in convergence has been experienced, more information than is generally required for post-plotting is output.

3.31 Subroutine WRTAX2

As for WRTAX1, except natural frequency and mode shape data are output.

3.32 Subroutine WRTAX3

As for WRTAX1, except strumming amplitudes and maximum segment responses are output.

3.33 Subroutine ZEROX

The mode number is determined by counting the zero crossings (see Section 2.2). ZEROX calculates analytically the number of zero crossings in each segment, then sums over all the segments to determine the mode number associated with the particular frequency.

3.34 Other Subroutines

Several subroutines are used in NATFREQ that have not yet been mentioned. These are grouped under the categories of plotting subroutines or site-specific subroutines.

The former include subroutines PLOT, PLOTS, NUMBER, SYMBOL, and AXIS. These are plotter dependent commands which reside in the host's plot library and are used to generate plot files. The user is directed to the manuals associated with the particular plotter for further information.

The latter category includes subroutines for calling the date, time, and for setting output printing widths. These, again, are site-specific and should not in general concern the user once the program has been correctly installed on the host computer (see installation instructions in Appendix V).

4. INPUT DATA SEQUENCE

4.1 Program Options

4.1.1 The Auxilliary Data File

NATFREQ contains an option for creating an auxilliary data file (ADF) on disk. The ADF contains data necessary to generate post-plots without performing all the calculations for the mode shapes and vortex shedding model again. Some additional data is included which may be useful for debugging cases where difficulties are encountered. This option was mainly included for the analysis of complex cable systems where the behavior of the system is beyond the range of intuition. In such cases it is difficult before running a problem to estimate a plotting range which will successfully illustrate regions of the cable which are undergoing significant motions. A first run is almost always required to isolate the cable sections where large displacements are occurring, then the ADF may be used as an input file with the desired plot parameters. This avoids executing the whole program again and is generally much cheaper.

The ADF is also very convenient to use on shorter problems. The file may be edited in the normal way and specified ranges may be given independently for different modes. This is not possible with a normal data file.

Another use of the ADF is debugging. It is not necessary, or desirable to clutter the main output file with calculated parameters such as α_i. These, however, may be useful for checking if a particular problem is not executing correctly or as expected.

It should be noted that the generation of an ADF is optional, and the default is no generation. However, for all but the simplest of problems, it is recommended that an ADF be created, even if it turns out that it is not used and is later deleted.

4.1.2 Boundary Condition Options

The boundary condition at the left hand end of the cable (i.e. x = 0), is always that the displacement is zero (See Equation 2-10.). The program is, however, set up to handle both fixed and free boundary conditions at the right hand end of the cable. The actual boundary condition is specified by the IBCODE parameter on the third input file line.

4.1.3 Printed Output Options

Depending on the nature of the problem, the detail and/or quantity of the output data required varies. For this reason, several output options are included, each giving a different type of output. The whole spectrum is covered from no output to a full output including specified location details. More information is given on the output data specification line described in 4.3.8.

4.1.4 Plotting Options

Three types of plot are produced by NATFREQ. The first is a plot of oscillation mode number versus Strouhal velocity. This is discussed more fully under "Subroutine RANGE" in Chapter 3. This plot may be produced alone or with either of the following two plot types.

The other two plot types are used for plotting the strumming response amplitude versus distance along the cable. "SCROLL" type outputs are generally large plots with a default abscissa length of 20 inches. They are fully labelled and titled. "SCROLL" is used when the plot is required to give reasonable detail at an easily read scale.

"PAGPLT" plots do essentially the same job as above, except the output is smaller, with an ordinate length of 2 inches and a default abscissa length of 10 inches. Labelling is minimized. The layout of the output is arranged so that three plots fit on a standard 8.5x11 inch sheet. Additional discussion of plot types is given in Chapter 3 under "Subroutine PAGPLT" and "Subroutine SCROLL". See also Chapter 7 for examples of the various types of plot.

When using the plotter, the program assumes that the pen is initially set at an origin at the lower left of the page, regardless of the plot type. The first command executed in the routine chosen resets this origin, and subsequent movements are allowed for accordingly.

4.2 Opening Output Files

Output from the program is directed to three separate files, corresponding to the standard output file, the plot file, and the ADF. These are assigned units 6, 7, and 8 respectively, and the appropriate channels should be opened before running the program. The default devices may be changed in the BLOCK DATA routine, if desired. If, for example, no ADF is to be written, it is unnecessary to open unit 8. However, ALWAYS open unit 6, as error messages generated while the program is running are written to that device.

4.3 Line by Line Input File Description

4.3.1 TITLE LINE

Cols	Variable	Type	Description
1-80	TITLE	Int	Job title or end of file. If the end of file is encountered, the job is terminated and plot files are closed.

4.3.2 INPUT DATA FILE TYPE CONTROL

Cols	Variable	Type	Description
1-5	IDAT	Int	IDAT = 0 ...standard input data file. IDAT = 1 ...auxiliary data file (see 4.1.1). (Automatically written in ADF.)

4.3.3 GENERAL PROBLEM INFORMATION

Cols	Variable	Type	Description
1-5	NSEG	Int	Total number of segments in the cable. The end of a segment is normally defined where a weight is added, or where cable properties change.
6-10	IBCODE	Int	Boundary condition code for right hand end of cable. IBCODE = 0 .....fixed end. IBCODE = 1 .....free end.
11-20	ZETA	Real	Fraction of internal structural critical damping for cable as measured in air.
21-30	RHOW	Real	Weight density of fluid (lb per cubic foot). Defaults to 64.0 lb per cubic foot (salt water density).

4.3.4 SEGMENT LENGTH DATA

Cols	Variable	Type	Description
1-10	CL(I)	Real	Length of Ith cable segment (ft.).
11-15	KG	Int	Generation parameter. KG gives the total number of consecutive segments (including this segment) with the same length as this segment. If KG=0, it is taken as 1.

NOTE : 1. The program keeps track of the number of generated segments. If more than NSEG are generated, an error message is printed.

2. Input all segment data as above before proceeding to 4.3.5. Sections 4.3.4, 4.3.5, and 4.3.6 are independent i.e. the number of lines needed in 4.3.4 is not necessarily the same as for 4.3.5.

4.3.5 SEGMENT PROPERTIES

Cols	Variable	Type	Description
1-10	D(I)	Real	Diameter (in.) of the Ith cable segment.
11-20	WC(I)	Real	Weight per unit length in air (including added fluid weight) of the Ith segment (lb/ft.).
21-30	TC(I)[1]	Real	Tension in Ith segment (lbs.).
31-40	CDC(I)	Real	Fluid drag coefficient for the Ith cable segment (non-strumming system).
41-45	KG	Int	Generation parameter. Gives the number of consecutive segments (including this segment) with the same properties as this segment. If KG=0, it is taken as 1.

NOTE : 1. The tension, TC(I), may need to be determined by a prior static analysis.

4.3.6 ATTACHED/SUSPENDED WEIGHT DATA

Cols	Variable	Type	Description
1-10	AW(I)	Real	Weight of attached mass, M_i (in air, including added fluid weight) at end of Ith cable segment (lb.). (See Figure 2.2).
11-20	STIF(I)	Real	Stiffness of attached spring at end of Ith segment (lb/ft.).
21-30	STWT(I)	Real	Weight of sprung mass, m_i (in air, including added fluid weight) at end of Ith segment (lb.). (See Figure 2.2).
31-40	CDA(I)	Real	Drag coefficient for added weight at end of Ith segment (sq. in.). (Non-strumming system).
41-50	PRA(I)	Real	Projected frontal area (sq. ft.) of the Ith attached weight, perpendicular to the flow direction.
51-60	DEFF(I)	Real	Effective diameter of the Ith attached weight (in.) measured perpendicular to both the flow and cable axis. Default : cable diameter.
61-65	KG	Int	Generation parameter. (See 4.3.5 for description.)

NOTE : Drag is not considered for sprung weights.

4.3.7 MODE SEARCH DATA

Cols	Variable	Type	Description
1-5	MXMDS[1]	Int	Maximum number of modes sought in the specified range, beginning with the lowest.
11-20	OMSTRT	Real	Lower limit of frequency search range. Units are given in UNITS parameter below.
21-30	OMSTOP[1]	Real	Upper limit of frequency search range. Units are given in UNITS parameter below.
31-40	DELOM	Real	Frequency search increment. Defaults to a value calculated by the program. Units are given by the UNITS parameter below.
41-50	ACC[2]	Real	Accuracy of convergence desired in mode search algorithm. Default = 0.005%.
51-55	UNITS	Int	Specifies the units of the input search parameters above. UNITS = 1 ...units are rad/sec. = 2 ...units are hertz. = 3 ...units are ft/sec. = 4 ...units are cm/sec. = 5 ...units are knots. The program searches in rad/sec. If UNITS = 3, 4, or 5, the Strouhal relationship is used to convert input units to search units.

NOTE : 1. The program terminates the search for frequencies when the maximum number of modes found is greater than MXMDS, or when the end of the search range is encountered, whichever occurs first.

2. Accuracy is defined as the ratio of A_{n+1} or B_{n+1} to the maximum cable modal amplitude, depending on whether the right hand end is fixed or free. The boundary condition is given by Equation 2-14a or 2-14b, depending on IBCODE in 4.3.3.

4.3.8 PRINTED OUTPUT SPECIFICATION

Cols	Variable	Type	Description
1-5	IAUX	Int	Specifies whether or not an ADF is written. IAUX = 0...No ADF written. = 1...ADF is written.
6-10	IOUTCD[1]	Int	Specifies type of output desired. IOUTCD = 0...No printed output. = 1...Full output including specified locations[2]. = 2...Full output, no specified locations. = 3...Summary output including specified locations. = 4...Summary output, no specified locations.
11-15	NSPEC	Int	If IOUTCD = 1 or 3 above, NSPEC gives the number of specified locations along the cable where response amplitude is desired.

NOTE : 1. If IOUTCD = 0, 2, or 4, NSPEC need not be specified and Section 4.3.9 is omitted.

2. A "specified location" is any point other than segment end locations where details of the output are desired.

4.3.9 LOCATIONS FOR SPECIFIED OUTPUT

Cols	Variable	Type	Description
1-10	SPLOC(I)	Real	Locations along cable for specified output, measured in feet from left hand end of cable. (See 4.3.8 and Chapter 5.)
11-20			
21-30			
etc.			

NOTE : Use as many lines as necessary to input NSPEC locations.

4.3.10 PLOTTED OUTPUT SPECIFICATION

Cols	Variable	Type	Description
1-5	IPLTCD	Int	Plotting option code. IPLTCD = 0...No plots. = 1..."Pagplt" type plot. = 2..."Scroll" type plot. = 3..."Pagplt" type, plus mode vs. velocity. = 4..."Scroll" type, plus mode vs. velocity. = 5...Mode vs. velocity only.
5-10	IPSPEC[1]	Int	Plot range option code. IPSPEC = 0...Plot entire cable length. IPSPEC = 1...Plot over specified segment range (see next input line).
11-20	PLEN	Real	Abscissa length, in inches. Defaults to 10" for "Pagplt" plots, and 20" for "Scroll" plots.

NOTE : 1. If IPSPEC = 0, omit the next input line.

4.3.11 PLOT RANGE SPECIFIERS

Cols	Variable	Type	Description
1-5	IPSTRT	Int	If IPSPEC = 1, gives segment number where plotting of output commences. I.e. the left hand end of the plotting range.
5-10	IPSTOP	Int	If IPSPEC = 1, gives segment number where plotting of output is terminated. I.e. the right hand end of the plotting range.

5. DESCRIPTION OF OUTPUT FILES

NATFREQ, as discussed in earlier chapters, produces two types of printed data files. The first, or standard output file, is the file containing the main output of the program, presented in an informative and easily read manner. The second, or auxiliary data file (ADF), presents program data which may be used for post-plotting applications or for debugging the program. The data in the ADF is generally presented in a less readable manner than the main output file. It contains some data considered unnecessary in the main output file, but which may be of use in some circumstances. Both file types are described below.

5.1 Standard Output File

The output from NATFREQ is divided into two main sections. The first contains general notes on the output and an echo of the input data. The second section, which varies in content depending on the option chosen, basically contains the frequency, response amplitude and drag coefficient data as calculated by the program.

5.1.1 Introductory Output Information

In all outputs, the following information is presented first. It is written in subroutine TITLRD, so if further notes are needed, or modifications made to those existing, only this routine need be modified.

The problem title as input in 4.3.1 is given, followed by the date and time as read from the clock on the host computer.

The program, as supplied, can be converted simply to double precision should the extra accuracy be found to be necessary. This would be achieved as described in Appendix V, while Chapter 6 discusses some reasons why it may be necessary. It is useful for the user to know whether the output is from a program run in single or double precision. This information follows the date and time on the output file.

A series of output notes is listed at this stage. It is often useful when viewing output to be able to clarify some points without having to refer back to the user manual. Several points which are considered to be most frequently queried are listed, and should be read before the remaining output data is viewed. More notes may be added to this series as discussed above for a particular site, or application.

5.1.2 Echo of Input Data

The data input as described in Chapter 4 is repeated at this stage. This is done for two main reasons; it allows this output file to present a full record of the problem, and secondly allows the user to check that the data was indeed input correctly. It is not uncommon to "slip a column" when constructing an input file, as experienced users will be well aware. The parameters listed have all been described already in Sections 4.3.3, 4.3.4, 4.3.5, and 4.3.6. An additional column contains arc length data. This is the total length of the cable system, up to the end of the current segment. It is calculated by the program as the individual segment lengths are read in by simply summing the individual lengths.

Several other input parameters are repeated: the total number of segments, the maximum number of modes sought, and the boundary condition at the right hand end of the cable assembly. The mode search limits in various units are printed in a tabular manner, along with the mode search increment as input or the default value calculated in the program. The fluid density and fraction of structural critical damping in air are repeated, followed by an effective fraction of structural critical damping in the fluid. Derivation of the latter value is described in Appendix III.

Two averages are given for drag coefficients based on the input information. These may be used later for comparison with the values modified by vortex shedding. The first is the average of the segment drag coefficients, weighted by the projected segment area, as given by Equation 2-40.

The second drag coefficient given is the average drag coefficient for the attached masses, again weighted by their projected areas. This average is defined in Equation 2-41.

5.1.3 Program Output Data

The natural frequencies, response amplitudes, and associated data are output in order of increasing mode number. At each mode number, if there is more than one diameter in the cable system, the data is output for each distinct diameter in turn.

The natural frequency in hertz and rad/sec is followed by the Strouhal velocity, corresponding to the particular diameter being excited, in ft/sec, cm/sec, and knots. The effective fraction of critical damping, considering both fluid and structural effects, as calculated in Appendix II is shown, then the effective mass parameter, given in Equation 2-35.

The maximum response amplitude over the whole cable assembly and its location is given, followed by the accuracy attained in the frequency search algorithm. The accuracy is defined as the ratio of magnitude of A_{n+1} or B_{n+1} to the maximum cable amplitude of response, as described above.

The iteration procedure ends in one of three ways :

- the end boundary condition is less than the input tolerance described in 4.3.7.
- the change in frequency calculated by the search algorithm is less than 10^{-12}
- the change in boundary condition from one iteration to the next is less than 10^{-12}

In most "normal" problems, the first condition will control. However, the second two conditions are included as it is found that in some larger problems, the accuracy requested may not be attainable, and the program could enter an infinite loop. The cutoff value of 10^{-12} is considered to be the limit of double precision accuracy for the machine. This value may be changed, if desired, in subroutine SEARCH. Note that whether or not the double precision version of the program is run, the subroutine SEARCH is double precision. If one of the second two conditions controls the exit from the search algorithm, it is useful to know what accuracy or convergence was attained.

The segment and attached weight response data are output segment by segment. An asterisk (*) beside a segment number indicates that the segment is active. That is, for that particular mode and flow velocity, that segment is being excited by vortex shedding. The drag coefficients for the cable and attached masses are the modified values due to drag amplification. The mass response amplitude is the actual amplitude of the cable at the ith mass location.

The maximum segment amplitude (second column) requires some clarification. Depending on the wavelength of the mode shape in a particular segment (see Equation 2-16), and the phase angle at the beginning of the segment, the maximum segment response is given either by the amplitude of the mode shape in the segment or by the response at either end. Thus the maximum segment response is NOT always the modal amplitude. An illustration of this point is given in Figure 5.1.

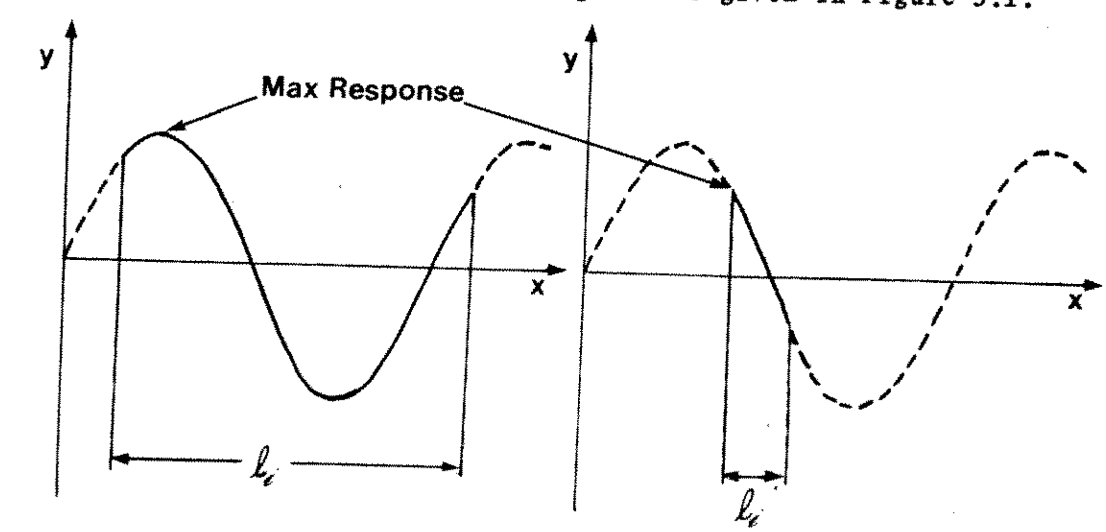


Figure 5.1. Maximum segment response

The new averages of drag coefficient for the cable and the attached weights are calculated in the same way as for the input data, except the modified coefficients are used (see Eqs 2-40 and 2-41). An overall average drag increase is then given, allowing for both the masses and the cable, once again weighted by projected area (Equation 2-44). This value gives perhaps the best measure of how much the drag of the entire system has been affected by the vortex induced motion of the cable system.

If the option for output at specified locations only is chosen, the output is similar to the segment information given above, except that the amplitudes of response are given only at the locations specified. The segment in which each location falls is listed, along with the data from that particular segment. This warns the user that although the response amplitude at a selected location may be small, the amplitude may be significantly larger elsewhere in the same segment.

If a "summary output" is requested, the above description is essentially the same, except the individual segment data is not presented.

5.2 Auxiliary Data File

As discussed in Chapter 4, the creation of an auxiliary data file (ADF) is an option available in NATFREQ. The ADF may be used for debugging purposes or post-plotting applications. The data in this file is in a less informative style than a regular output file. This is a consequence of the purpose for which the file is intended. The contents of the file are discussed below.

5.2.1 Input Data Echo

The first line of the ADF contains the title for the problem, as read in the first line of a normal data file. The second line contains simply a "1" in the fifth column. This digit instructs the program to process an ADF as opposed to a regular input data file.

General plotting specification data follows : the total number of segments, the plotting option code and plot abscissa length (see 4.3.10). The parameter "NCOUNT" gives the total number of output cases in the file, and is the product of the number of modes found and the number of distinct diameters. The input parameters necessary for post-plotting follow : segment lengths, diameters, added weights, etc.

5.2.2 Natural Frequency and Mode Shape Data

The natural frequency and "raw" mode shape data is written for each mode before the modal amplitudes are scaled to account for the vortex shedding model. This includes a count of the number of iterations made in the search algorithm before convergence is attained. The parameters IPSTRT and IPSTOP have the same meaning as in Section 4.3.11, and may be changed by editing the file to give plots over specified ranges for each distinct mode. Although the only segment data needed for post-plotting from this section is the parameter PHAS(I), several other modal parameters are listed also. These are values considered useful for the other application of the ADF such as debugging. It may be possible to trace problems encountered in running a certain problem by examining these values. The number in the last position of the "A(I)" column is the end boundary condition attained. Comparing this value with those in the AMPL(I), A(I), and B(I) columns gives an idea of the accuracy achieved in the algorithm for natural frequency determination.

5.2.3 Response Amplitude Data

A nonzero value in the next line indicates the the next lines of file contain response amplitude data for the particular mode and shedding diameter given. The A(I+1) column contains the amplitudes at the location of the ith attached weights. This is not re-read, but may be of interest in debugging. The columns RAMP(I) and SEGSIR(I) contain the segment modal response amplitudes and maximum segment responses respectively for the scaled mode shape.

The output format of the ADF is controlled so that the program interprets the blocks of data correctly. Do not delete any lines from the file or modify the formatting within it, whether the line is blank or not. This may cause the program to abort, unless corresponding modifications are made therein.

5.3 Plotted Output

Examples of the types of plotted output available are given in Chapter 7 and the user is referred to these to follow while reading this section. The overall structure of the plots has been discussed in Chapters 3 and 4, so these details are not repeated here.

Both of the response amplitude vs. distance along cable plots have some properties in common. First, the plotted ordinate is the actual response amplitude after the shedding model has been applied, not the uncorrected mode shape. The plots are automatically scaled in the program using the maximum response amplitude as described in 5.1.3.

Asterisks show the position of attached masses and circles the location of spring-mass units. If no attachments are present, a tick mark shows the end of a segment. The mode number and Strouhal velocity for the particular mode drawn are given.

5.3.1 Pagplt Type Plots

An example of a "Pagplt" type plot is given in Figure 7.2. A major purpose for this type of plot was to present a reasonably simple, sparsely labelled output. For this reason, only the plot description, mode number, and Strouhal velocity in knots are given. More information, such as that given in the "Scroll" plots was suppressed to maintain this simplicity. Only the arc length values at the ends of the plot range, and the center are written on the ordinate axis.

5.3.2 Scroll Type Plots

As described above, the detail in labelling of these plots is greater than in the "Pagplt" plots. The natural frequency of the mode is given in hertz as well as the Strouhal velocity in knots, found from the shedding diameter which is also printed. The plotting range in terms of beginning and ending segments is written. The abscissa is divided into one inch increments, therefore, care should be taken when specifying the "PLEN" value in 4.3.10 so as to get suitable arc length increments. An example is shown in Figure 7.4.

5.3.3 Mode Number vs. Velocity Plots

The plot and run title are written at the top of the plot. The run title is written in two 40 column lines, so care in formatting the title name on the first input card can lead to a centered title. A key of the symbols used is included on the plot, listing the symbol against the shedding diameter to which it corresponds.

The ordinate axis of the plot is mode number. Its range and increment are automatically calculated by NATFREQ. The abscissa is the Strouhal velocity associated with the mode and shedding diameter plotted. If the input units (4.3.7) are hertz, rad/sec or knots, the velocity is given in knots. If the input units are in ft/sec or cm/sec, the velocity is given in the corresponding units. The upper and lower limits of the abcissa are as input by the user (see 4.3.7). If the maximum number of modes, MXMDS, is reached before the upper search limit is encountered, further modes are not found. The plot axis limits were selected so as to indicate to the user whether or not the given range is adequately covered by the maximum number of modes sought.

The number of zero crossings does not increase by one each time a solution satisfying the right hand end boundary condition is found, (a mode of the system) if spring-mass attachments are present. For this reason, the usefulness of a mode number vs. velocity plot is limited, and care should be exercised in using them in these situations. This is illustrated in the third example of Chapter 7.

6. ACCURACY AND CONVERGENCE

There are several places in NATFREQ where convergence difficulties may be encountered. This chapter outlines some of these areas and other possible difficulties which might arise. Potential problems are discussed and an option described which may correct or improve these problems.

In the coding of NATFREQ, every effort has been made to make all of the algorithms as efficient and accurate as possible. This necessitates making some routines and variables double precision, even if the rest of the program is run in single precision. During the development, many different example problems have been run. When a weakness was discovered, the algorithm was examined, and corrected or improved where possible. In addition, a check was included in the program and provision was made for the printing of a warning message should the particular difficulty be encountered.

6.1 Convergence in the Natural Frequency Algorithm

The shooting technique used in NATFREQ has several advantages over standard matrix methods commonly used for natural frequency determination. The two most significant perhaps are storage requirements and accuracy. The technique is, however, limited in the size of problems it can handle. As the modal parameters in one segment depend on those calculated in all the preceding segments (see Eqs 2-6 and 2-9), a certain amount of round-off error is accumulated as the computation proceeds. For very complex cable systems, with many segments, this accumulation can lead to a non-converging solution. That is, the boundary condition at the right hand end cannot be satisfied to the required accuracy.

The propagation and growth of the roundoff induced instability can be clearly seen in some cases. Much of the development of the program was done on a PRIME computer, which has a smaller word size than CDC machines. The roundoff problem was, therefore, accentuated. However, use of the smaller word size did point to the type of problems that might be expected in some circumstances. A test case with 380 cable segments gave some quite severe convergence problems. Divergence could be seen to start occurring at about the 340th segment, and then grow so that the boundary condition at the right hand end was at times of similar magnitude to the maximum cable system response (see Figure 6.1).

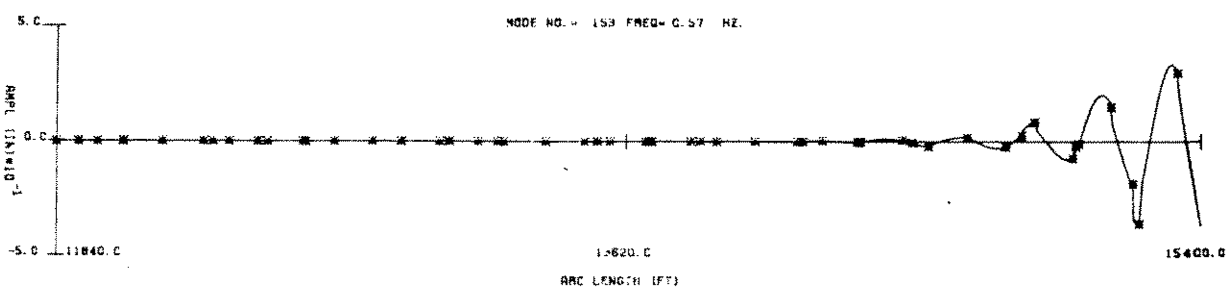


Figure 6.1. Non-convergence in mode shape algorithm

The significant computation associated with the shooting algorithm is performed in subroutine SOLV. To maximize the problem size, and give the best accuracy possible, this routine has been made double precision, regardless of the precision of the rest of the program. It was found that the additional precision introduced by making the whole program double precision was sometimes significant. Each subroutine consequently contains a block of commented lines containing statements necessary to make the routine double precision. If the user has convergence or accuracy problems when running NATFREQ, the double precision version could be tried by uncommenting all of the lines just described, recompiling and re-running the program. The whole program must be altered, not just selected routines, or it will not run. This is discussed further in Appendix V.

It should be emphasized that the program does have accuracy limitations. If a large problem of over 100 segments is run,the accuracy attained is likely to be less than for a problem of less than ten segments. However, it is believed that in general the accuracy achieved is sufficient. The user should not be overly concerned if an arbitrarily small accuracy limit, such as the default value, cannot be achieved. Always try to specify an accuracy value that is realistic and appropriate to the problem at hand.

6.2 Convergence in the Newton-Raphson Damping Calculation

If convergence problems are encountered, it is recommended that the user try double precisioning the entire program, as described in the last section and in Appendix V. If there is still a problem, and the input data has been thoroughly checked, it may be necessary to check the subroutine (subroutine DAMP) in question. This should be done using the computer's debugging facility, if available, or by attempting to trace by hand, with the given data, through the routine to see if the problem can be pinpointed. Problems of this type are best picked up by sketching the function under consideration, then following the solution procedure, as outlined in Appendix II, graphically.

6.3 Incorrect Mode Number Computation

It has been observed in some applications (particularly for high mode numbers of systems with many segments) that a discrepancy in the number of zero crossings may occur, and hence the mode number may occasionally be given incorrectly. This problem takes the form of having an apparently missed mode, followed by two different mode shapes both with the next highest mode number.

It is believed that this problem is a consequence of convergence accuracy problems. If a mode does not converge sufficiently, it is possible that a zero crossing will be missed, or that an extra zero will be added due to the non-zero end boundary condition. An optional correction has been included in subroutine ZEROX which may in some cases alleviate this problem. The user is directed to Appendix V for installation of this option. In general, for high mode numbers, caution should be exercised when requesting data for one mode only. Several modes on either side of the desired mode should be obtained, so that the mode sought can be checked in the context of the nearby modes. Modes are usually in the correct sequence, and their frequency and mode shape are correct; it is only the mode number that may be in error.

7. SAMPLE PROGRAM OUTPUTS

Three sets of example problems are presented in this chapter. Each one illustrates an important feature or features available in NATFREQ. While it is not possible to cover every option, it is felt that the examples will acquaint the user with the most often used types of output and analyses available. It is recommended that the reader follow the input data descriptions in Chapter 4 to verify the options chosen for each input data file.

7.1 Example 1

7.1.1 Example 1(a)

The problem consists of six equal masses on a uniform cable with unequal segment lengths as shown in Figure 7.1. The problem is run from the standard data file (Table 7.1). An ADF is not written. The standard output file contains a full output, including specified locations. Plots are of the "Pagplt" type, over the full length of the cable, and a mode vs. velocity plot is requested. Six modes are sought.

The main output file appears in Table 7.2, and the plotted output in Figures 7.2 and 7.3. Note that the main output file has been reformatted somewhat before being presented here. The listing is usually continous, not on separate pages as given. The page listing is used in this and subsequent examples purely for clarity of display.

7.1.2 Example 1(b)

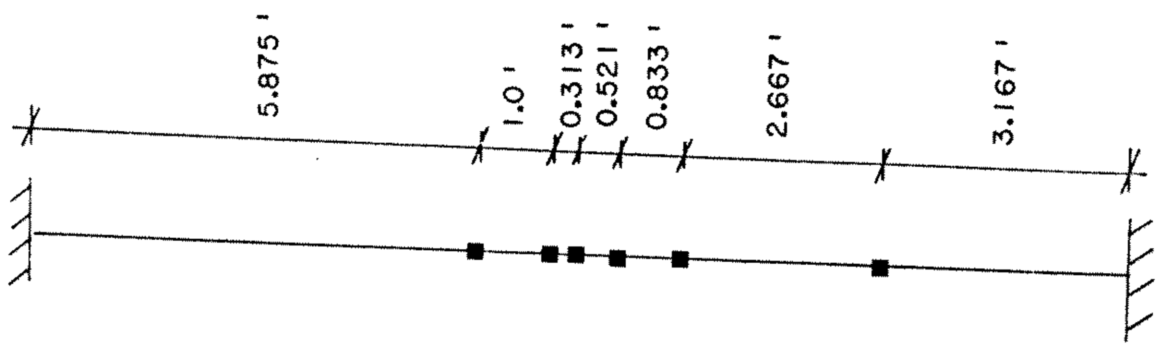
In order to illustrate the range of output options available, the same example is run from the data file given in Table 7.3, with the exceptions that an ADF is written, the main output is in suppressed form, and the plots are of the "Scroll" type, with an axis length of 13 inches (note that the plot has been reduced for publication). The maximum number of modes sought is reduced from six to three. The main output is given in Table 7.4 and the plots in Figure 7.4. The ADF is listed in Table 7.5.

7.1.3 Example 1(c)

The ADF in Table 7.5 from Example 1(b) has been edited in Table 7.6 to produce "Pagplt" plots over specified segment ranges. The IPLTCD (labeled NPLOT in ADF), IPSTRT and IPSTOP parameters reflect the changes made to the file. The plots resulting from re-running the program from this ADF as a data file are shown in Figure 7.5.

7.1.4 Example 1(d)

As a final illustration of the output options in this section, another mode vs. velocity plot is included (Figure 7.6). This was generated from a similar data file, except that three distinct diameters were input instead of one and twelve modes were sought (Table 7.7). All options and output except the mode vs. velocity plot were suppressed. This case is a good illustration of the use of the mode vs. velocity plot to determine modes and shedding diameters of interest over a specified velocity range, and/or to warn the user that the modal superposition may be necessary. The model for vortex shedding assumes no modal coupling. Several modes at, or near, a certain flow velocity means that modal interaction will probably be significant. In this case, root-sum-square combination of modal amplitudes might give a more appropriate measure of the system response than a single mode.



DIAMETER : 0.033 " (CONST.)

TENSION : 5.52 LB (CONST.)

WEIGHT/LENGTH : 0.002805 LB/FT (CONST.)

ADDED WEIGHT : 0.004154 LB/FT (CONST.)

FIGURE 7.1 EXAMPLE 1

```
SIX MASS EXAMPLE- FIXED END TEST                         ORIGINAL CABLE
    7                  62.4
     5.875
       1.0
      .313
      .521
      .833
     2.667
     3.167
      .033  2.805E-3    5.52       1.0     7
  4.154E-3
         6      65.0   200.0       0.0              2        6
   0     1    4
       2.5       5.0     7.5      10.0
   3
```

TABLE 7.1 EXAMPLE 1(A) – INPUT DATA FILE

SIX MASS EXAMPLE- FIXED END TEST   ORIGINAL CABLE

DATE - WED, MAR 28 1984 TIME - 23:25:23

+++++++++PROGRAM RUNNING IN SINGLE PRECISION+++++++++

N O T E S   O N   O U T P U T   D A T A

1. ALL WEIGHTS ARE TOTAL EFFECTIVE WEIGHTS AND INCLUDE EFFECTS OF ADDED WATER MASS.

2. MODE SEARCH VELOCITY LIMITS CALCULATED FROM STROUHAL'S RELATIONSHIP USE MIN. DIAMETER FOR LOWER LIMIT AND MAX. DIAMETER FOR UPPER LIMIT AND INCREMENT.

3. DRAG IS NOT CALCULATED ON SPRUNG MASSES.

4. TABULATED RESPONSE AMPLITUDES ARE ONE HALF OF THE PEAK TO PEAK RESPONSE.

5. IN THE OUTPUT DATA, AN ASTERISK (*) BESIDE A SEGMENT NO. INDICATES THAT THIS SEGMENT IS ACTIVE FOR THE PARTICULAR MODE AND FLOW VELOCITY, I.E. IT IS BEING EXCITED BY VORTEX SHEDDING.

INPUT DATA SET NO. 1

SEGMENT DEFINITION			CABLE SEGMENT DATA				ATTACHED WEIGHT DATA				SPRUNG WT DATA	
SEG NO	LENGTH (FT)	ARC LENGTH (FT)	DIAM (IN)	DRAG COEF	WT/LENGTH (LB/FT)	TENSION (LB)	ATTACHED WT (LB)	DRAG COEF	PROJ AREA (FT**2)	EFFECT DIA (IN)	ATT SPR (LB/FT)	SPRUNG WT (LB)
1	5.875	5.875	3.300E-02	1.00	2.805E-03	5.52	4.154E-03	0.00	0.000E-01	3.300E-02	0.00	0.00
2	1.000	6.875	3.300E-02	1.00	2.805E-03	5.52	4.154E-03	0.00	0.000E-01	3.300E-02	0.00	0.00
3	0.313	7.188	3.300E-02	1.00	2.805E-03	5.52	4.154E-03	0.00	0.000E-01	3.300E-02	0.00	0.00
4	0.521	7.709	3.300E-02	1.00	2.805E-03	5.52	4.154E-03	0.00	0.000E-01	3.300E-02	0.00	0.00
5	0.833	8.542	3.300E-02	1.00	2.805E-03	5.52	4.154E-03	0.00	0.000E-01	3.300E-02	0.00	0.00
6	2.667	11.209	3.300E-02	1.00	2.805E-03	5.52	4.154E-03	0.00	0.000E-01	3.300E-02	0.00	0.00
7	3.167	14.376	3.300E-02	1.00	2.805E-03	5.52	0.000E-01	0.00	0.000E-01	3.300E-02	0.00	0.00

TOTAL NO OF SEGMENTS = 7

AVERAGE CABLE DRAG COEF = 1.000 BASED ON PROJECTED CABLE AREA OF 3.953E-02 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 6 MASSES AND PROJECTED AREA OF 0.000E-01 (FT**2)

TABLE 7.2 EXAMPLE I(A) – OUTPUT DATA FILE

MAXIMUM NO OF MODES SOUGHT = 6

BOUNDARY CONDITION AT END OF LAST SEGMENT : FIXED

MODE SEARCH LIMITS

	LOWER LIMIT	UPPER LIMIT	INCREMENT
KNOTS	0.5040	1.5507	0.0011
HERTZ	65.0000	200.0000	0.1393
FT/SEC	0.8512	2.6190	0.0018
CM/SEC	25.9443	79.8286	0.0556
RAD/SEC	408.4070	1256.6370	0.8755

FRACTION OF STRUCTURAL CRITICAL DAMPING IN AIR = 0.0000

FLUID DENSITY = 6.240E 01 (LB/FT*3)

FRACTION OF STRUCTURAL CRITICAL DAMPING IN FLUID = 0.0000

TABLE 7.2 (CTD.)

MODE NO 10

FREQUENCY = 4.219E 02 RAD/SEC
= 6.715E 01 HERTZ

AVERAGE STROUHAL VELOCITY BASED ON DIAMETER OF 3.300E-02 IN. 8.794E-01 FT/SEC
2.680E 01 CM/SEC
5.207E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING = 0.000E-01 EFFECTIVE MASS PARAMETER = 8.621E 00

MAX DISPLACEMENT = 4.105E-02 OCCURING IN SEGMENT NUMBER 1

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) = -0.000 %

CABLE RESPONSE			MASS RESPONSE		
SEGMENT NO	MAX SEG AMPL (IN)	DRAG COEF	MASS RESP AMPL (IN)	DRAG COEF ATT WTS.	SPRING MASS NAT FREQ (HZ)
1 *	4.105E-02	2.472	1.683E-02	0.000	0.000
2 *	1.683E-02	1.707	6.065E-03	0.000	0.000
3 *	6.188E-03	1.608	5.863E-03	0.000	0.000
4 *	8.904E-03	1.433	8.904E-03	0.000	0.000
5 *	8.904E-03	1.442	5.336E-03	0.000	0.000
6 *	6.254E-03	1.406	1.887E-03	0.000	0.000
7 *	2.279E-03	1.239	1.026E-07	BOUNDARY	BOUNDARY

AVERAGE CABLE DRAG COEF = 1.833 BASED ON PROJECTED CABLE AREA OF 3.953E-02 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 6 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) = 83.305%

RESPONSE AMPLITUDES AT 4 SPECIFIED LOCATIONS. DISTANCES FROM LEFT END OF CABLE ASSEMBLY

SPECIFIED LOCN (FT)	IN SEGMENT	RESP. AMPL (IN)	SEG RESP AMPL (IN)	SEGMENT DRAG COEF
2.50	1 *	3.558E-02	4.105E-02	2.472
5.00	1 *	3.549E-02	4.105E-02	2.472
7.50	4 *	3.177E-03	8.904E-03	1.433
10.00	6 *	6.184E-03	6.254E-03	1.406

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TABLE 7.2 (CTD.)

MODE NO 11

FREQUENCY = 5.209E 02 RAD/SEC   AVERAGE STROUHAL VELOCITY 1.086E 00 FT/SEC
= 8.290E 01 HERTZ   BASED ON DIAMETER 3.309E 01 CM/SEC
OF 3.300E-02 IN. 6.428E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING = 0.000E-01   EFFECTIVE MASS PARAMETER = 8.157E 00

MAX DISPLACEMENT = 4.101E-02 OCCURING IN SEGMENT NUMBER 7

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) = -0.000 %

	CABLE RESPONSE		MASS RESPONSE		
SEGMENT NO	MAX SEG AMPL (IN)	DRAG COEF	MASS RESP AMPL (IN)	DRAG COEF ATT WTS.	SPRING MASS NAT FREQ (HZ)
1 *	1.042E-03	1.141	4.145E-04	0.000	0.000
2 *	2.265E-03	1.228	2.154E-03	0.000	0.000
3 *	2.687E-03	1.205	2.687E-03	0.000	0.000
4 *	2.687E-03	1.253	2.899E-04	0.000	0.000
5 *	3.794E-03	1.314	3.783E-03	0.000	0.000
6 *	1.247E-02	1.692	1.095E-02	0.000	0.000
7 *	4.101E-02	2.465	1.704E-07	BOUNDARY	BOUNDARY

AVERAGE CABLE DRAG COEF = 1.556 BASED ON PROJECTED CABLE AREA OF 3.953E-02 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 6 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) = 55.633%

RESPONSE AMPLITUDES AT 4 SPECIFIED LOCATIONS. DISTANCES FROM LEFT END OF CABLE ASSEMBLY

SPECIFIED LOCN (FT)	IN SEGMENT	RESP. AMPL (IN)	SEG RESP AMPL (IN)	SEGMENT DRAG COEF
2.50	1 *	9.333E-04	1.042E-03	1.141
5.00	1 *	8.302E-04	1.042E-03	1.141
7.50	4 *	1.476E-03	2.687E-03	1.253
10.00	6 *	5.229E-03	1.247E-02	1.692

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TABLE 7.2 (CTD.)

MODE NO 12

FREQUENCY = 5.405E 02 RAD/SEC
= 8.603E 01 HERTZ

AVERAGE STROUHAL VELOCITY 1.127E 00 FT/SEC
BASED ON DIAMETER 3.434E 01 CM/SEC
OF 3.300E-02 IN. 6.670E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING = 0.000E-01 EFFECTIVE MASS PARAMETER = 1.340E 01

MAX DISPLACEMENT = 4.130E-02 OCCURING IN SEGMENT NUMBER 3

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) = 0.003 %

CABLE RESPONSE			MASS RESPONSE		
SEGMENT NO	MAX SEG AMPL (IN)	DRAG COEF	MASS RESP AMPL (IN)	DRAG COEF ATT WTS.	SPRING MASS NAT FREQ (HZ)
1 *	3.669E-02	2.395	1.801E-03	0.000	0.000
2 *	3.097E-02	2.406	2.494E-02	0.000	0.000
3 *	4.130E-02	2.152	4.130E-02	0.000	0.000
4 *	4.130E-02	2.162	1.738E-02	0.000	0.000
5 *	1.738E-02	1.769	4.653E-03	0.000	0.000
6 *	5.055E-03	1.380	2.908E-03	0.000	0.000
7 *	5.882E-03	1.411	1.261E-06	BOUNDARY	BOUNDARY

AVERAGE CABLE DRAG COEF = 1.940 BASED ON PROJECTED CABLE AREA OF 3.953E-02 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 6 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) = 94.048%

RESPONSE AMPLITUDES AT 4 SPECIFIED LOCATIONS. DISTANCES FROM LEFT END OF CABLE ASSEMBLY

SPECIFIED LOCN (FT)	IN SEGMENT	RESP. AMPL (IN)	SEG RESP AMPL (IN)	SEGMENT DRAG COEF
2.50	1 *	2.908E-02	3.669E-02	2.395
5.00	1 *	3.547E-02	3.669E-02	2.395
7.50	4 *	7.923E-03	4.130E-02	2.162
10.00	6 *	4.631E-03	5.055E-03	1.380

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TABLE 7.2 (CTD.)

MODE NO 13

FREQUENCY = 5.574E 02 RAD/SEC   AVERAGE STROUHAL VELOCITY 1.162E 00 FT/SEC
= 8.872E 01 HERTZ   BASED ON DIAMETER 3.541E 01 CM/SEC
OF 3.300E-02 IN. 6.879E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING = 0.000E-01   EFFECTIVE MASS PARAMETER = 1.258E 01

MAX DISPLACEMENT = 4.176E-02 OCCURING IN SEGMENT NUMBER 1

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) = 0.000 %

	CABLE RESPONSE		MASS RESPONSE		
SEGMENT NO	MAX SEG AMPL (IN)	DRAG COEF	MASS RESP AMPL (IN)	DRAG COEF ATT WTS.	SPRING MASS NAT FREQ (HZ)
1 *	4.176E-02	2.496	1.791E-02	0.000	0.000
2 *	2.757E-02	2.023	2.757E-02	0.000	0.000
3 *	3.546E-02	2.089	3.546E-02	0.000	0.000
4 *	3.546E-02	2.061	1.348E-02	0.000	0.000
5 *	1.349E-02	1.674	3.103E-03	0.000	0.000
6 *	4.282E-03	1.347	1.798E-03	0.000	0.000
7 *	2.696E-03	1.248	1.822E-07	BOUNDARY	BOUNDARY

AVERAGE CABLE DRAG COEF = 1.903 BASED ON PROJECTED CABLE AREA OF 3.953E-02 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 6 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) = 90.268%

RESPONSE AMPLITUDES AT 4 SPECIFIED LOCATIONS. DISTANCES FROM LEFT END OF CABLE ASSEMBLY

SPECIFIED LOCN (FT)	IN SEGMENT	RESP. AMPL (IN)	SEG RESP AMPL (IN)	SEGMENT DRAG COEF
2.50	1 *	2.838E-02	4.176E-02	2.496
5.00	1 *	4.164E-02	4.176E-02	2.496
7.50	4 *	7.924E-03	3.546E-02	2.061
10.00	6 *	3.348E-03	4.282E-03	1.347

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TABLE 7.2 (CTD.)

MODE NO 14

FREQUENCY = 6.396E 02 RAD/SEC = 1.018E 02 HERTZ

AVERAGE STROUHAL VELOCITY BASED ON DIAMETER OF 3.300E-02 IN. 1.333E 00 FT/SEC 4.063E 01 CM/SEC 7.893E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING = 0.000E-01 EFFECTIVE MASS PARAMETER = 8.612E 00

MAX DISPLACEMENT = 4.237E-02 OCCURING IN SEGMENT NUMBER 6

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) = -0.002 %

	CABLE RESPONSE		MASS RESPONSE		
SEGMENT NO	MAX SEG AMPL (IN)	DRAG COEF	MASS RESP AMPL (IN)	DRAG COEF ATT WTS.	SPRING MASS NAT FREQ (HZ)
1 *	2.610E-04	1.057	1.837E-04	0.000	0.000
2 *	8.957E-04	1.130	6.471E-04	0.000	0.000
3 *	1.728E-03	1.145	1.728E-03	0.000	0.000
4 *	3.360E-03	1.232	3.360E-03	0.000	0.000
5 *	1.056E-02	1.592	1.030E-02	0.000	0.000
6 *	4.237E-02	2.463	1.038E-02	0.000	0.000
7 *	1.057E-02	1.629	1.010E-06	BOUNDARY	BOUNDARY

AVERAGE CABLE DRAG COEF = 1.488 BASED ON PROJECTED CABLE AREA OF 3.953E-02 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 6 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) = 48.817%

RESPONSE AMPLITUDES AT 4 SPECIFIED LOCATIONS. DISTANCES FROM LEFT END OF CABLE ASSEMBLY

SPECIFIED LOCN (FT)	IN SEGMENT	RESP. AMPL (IN)	SEG RESP AMPL (IN)	SEGMENT DRAG COEF
2.50	1 *	1.795E-05	2.610E-04	1.057
5.00	1 *	3.581E-05	2.610E-04	1.057
7.50	4 *	1.566E-03	3.360E-03	1.232
10.00	6 *	1.322E-02	4.237E-02	2.463

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TABLE 7.2 (CTD.)

MODE NO 15

FREQUENCY = 6.816E 02 RAD/SEC AVERAGE STROUHAL VELOCITY 1.421E 00 FT/SEC
= 1.085E 02 HERTZ BASED ON DIAMETER 4.330E 01 CM/SEC
OF 3.300E-02 IN. 8.411E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING = 0.000E-01 EFFECTIVE MASS PARAMETER = 7.767E 00

MAX DISPLACEMENT = 3.883E-02 OCCURING IN SEGMENT NUMBER 1

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) = 0.001 %

	CABLE RESPONSE		MASS RESPONSE		
SEGMENT NO	MAX SEG AMPL (IN)	DRAG COEF	MASS RESP AMPL (IN)	DRAG COEF ATT WTS.	SPRING MASS NAT FREQ (HZ)
1 *	3.883E-02	2.439	7.696E-03	0.000	0.000
2 *	1.054E-02	1.627	3.952E-03	0.000	0.000
3 *	3.952E-03	1.249	1.937E-03	0.000	0.000
4 *	1.937E-03	1.172	4.652E-04	0.000	0.000
5 *	4.959E-04	1.083	1.613E-04	0.000	0.000
6 *	2.400E-04	1.050	4.802E-05	0.000	0.000
7 *	6.422E-05	1.023	3.303E-07	BOUNDARY	BOUNDARY

AVERAGE CABLE DRAG COEF = 1.663 BASED ON PROJECTED CABLE AREA OF 3.953E-02 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 6 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) = 66.276%

RESPONSE AMPLITUDES AT 4 SPECIFIED LOCATIONS, DISTANCES FROM LEFT END OF CABLE ASSEMBLY

SPECIFIED LOCN (FT)	IN SEGMENT	RESP. AMPL (IN)	SEG RESP AMPL (IN)	SEGMENT DRAG COEF
2.50	1 *	1.814E-02	3.883E-02	2.439
5.00	1 *	3.208E-02	3.883E-02	2.439
7.50	4 *	6.995E-04	1.937E-03	1.172
10.00	6 *	1.666E-05	2.400E-04	1.050

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TABLE 7.2 (CTD.)

FIGURE 7.2 EXAMPLE I(A) – PLOTTED OUTPUT

TITLE PAGE

SIX MASS EXAMPLE - FIXED END TEST
ØRIGINAL CABLE

FIGURE 7.2 (CTD.)

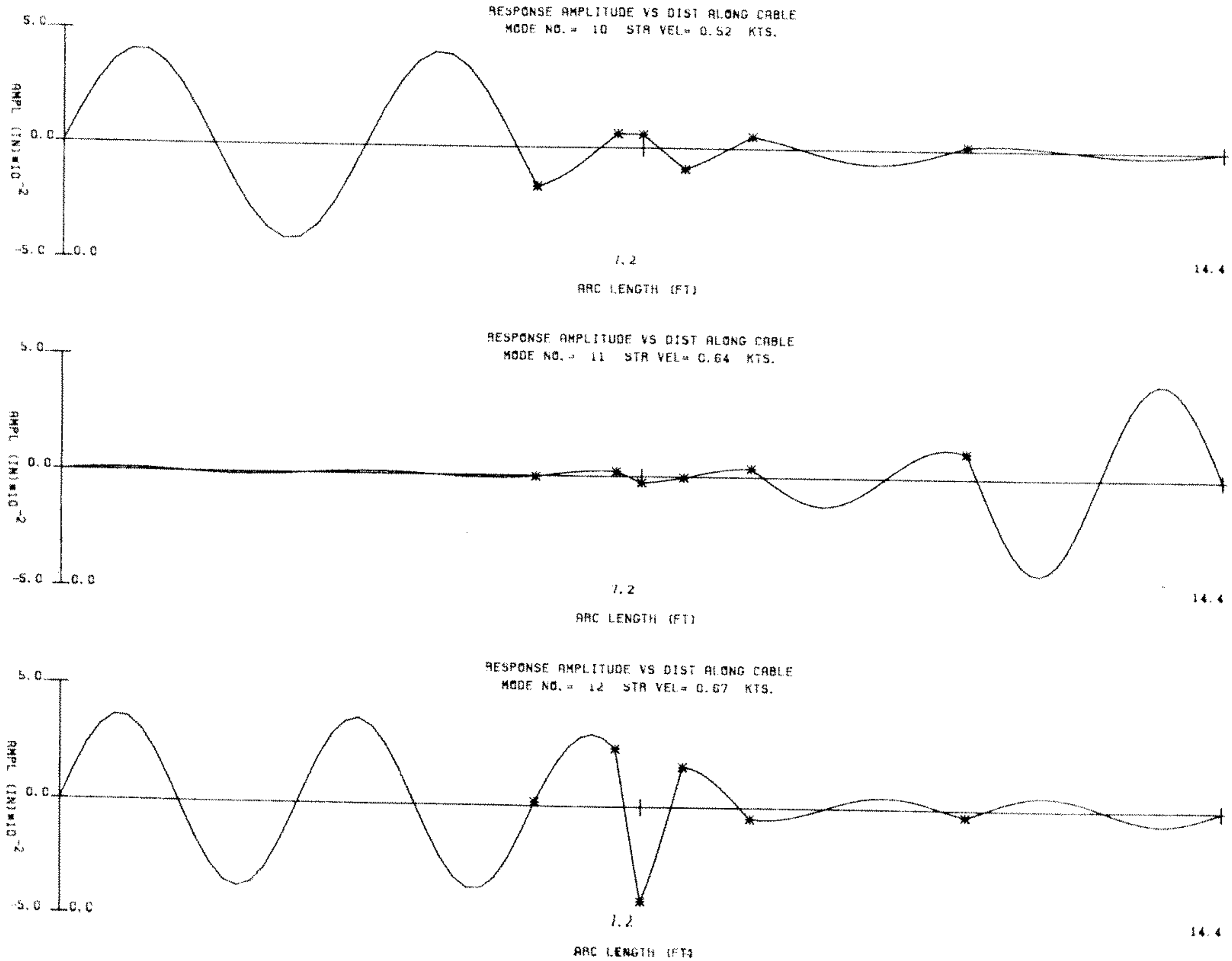


FIGURE 7.2 (CTD.)

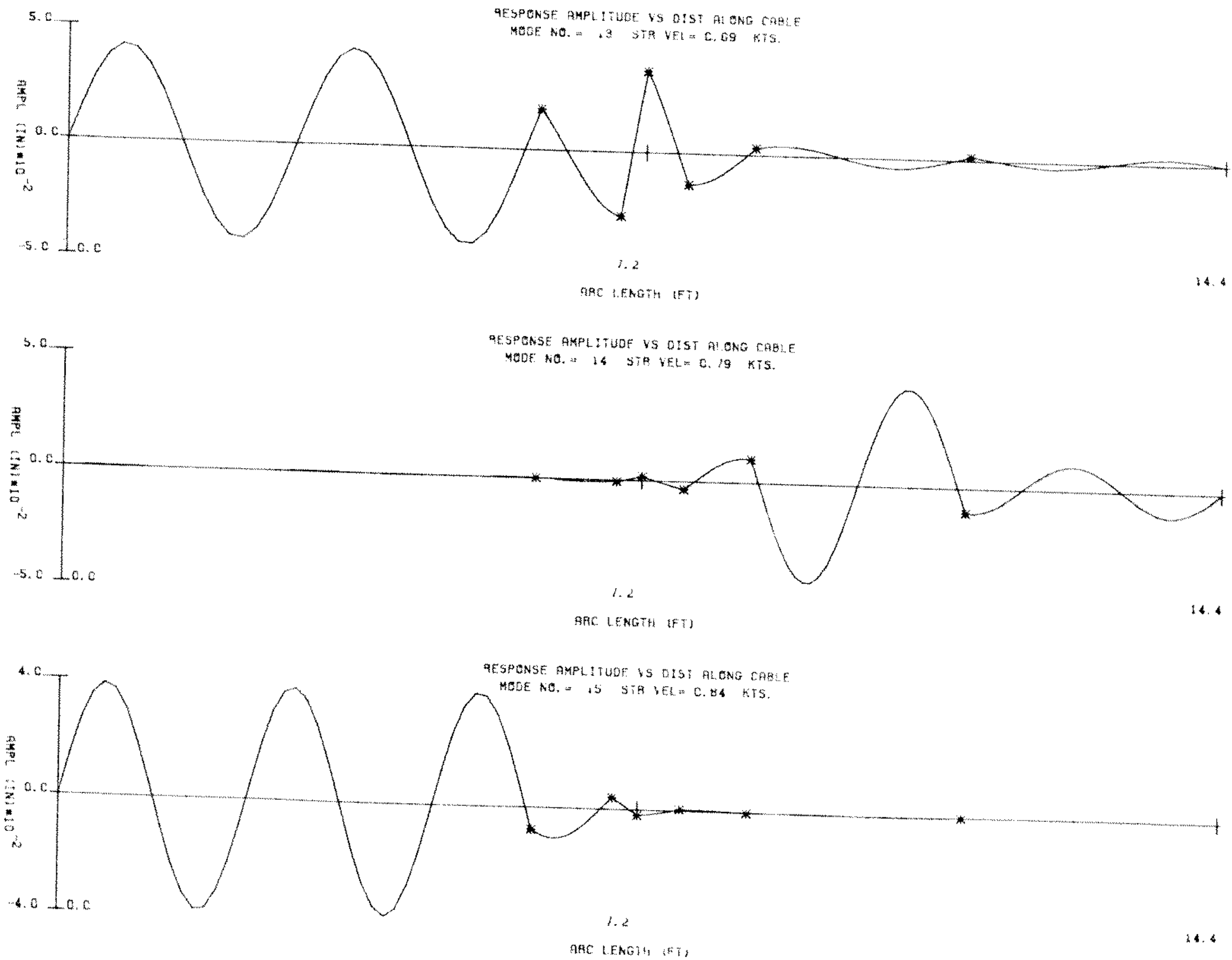
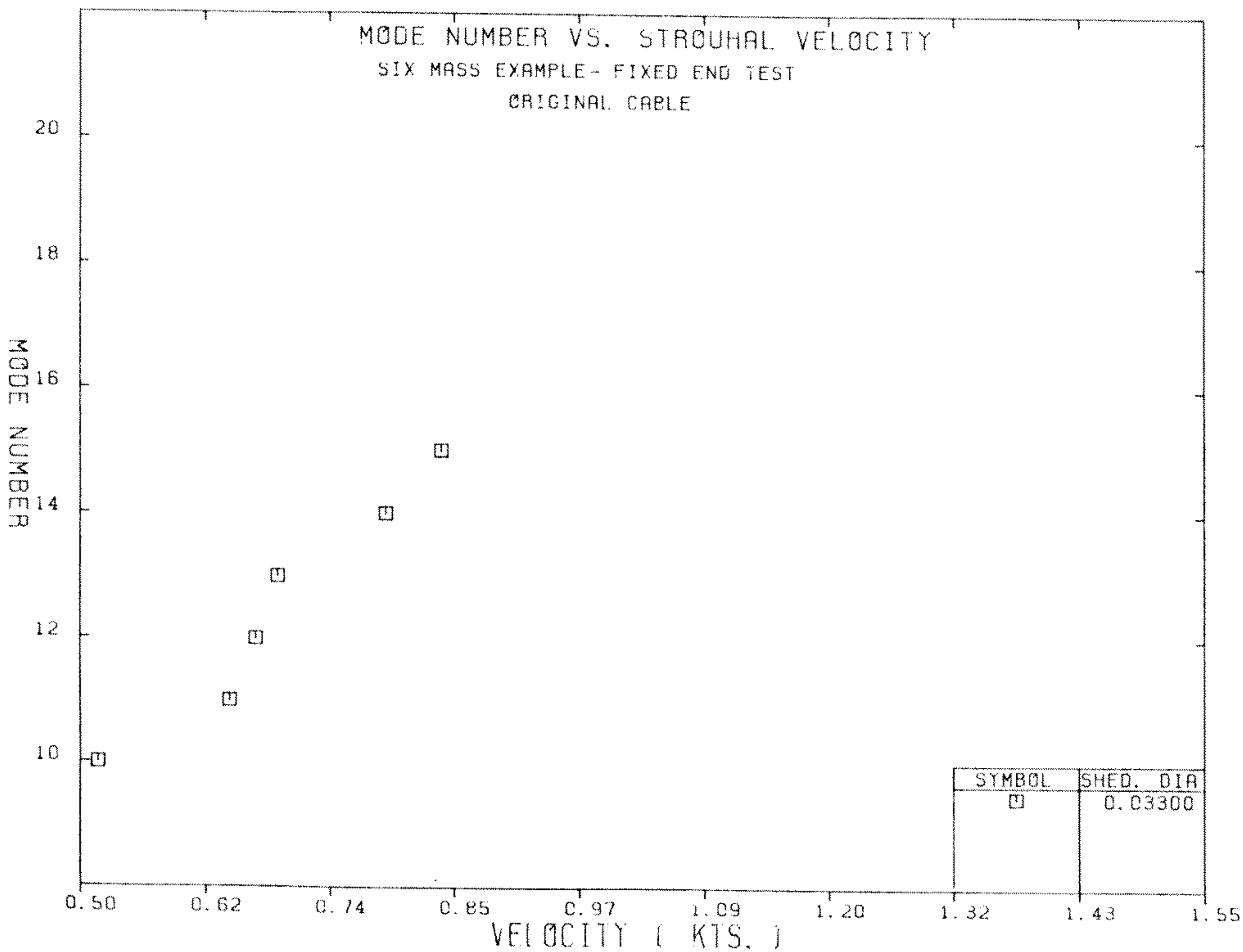


FIGURE 7.3 EXAMPLE I (A) – MODE VS. VELOCITY PLOT



```
SIX MASS EXAMPLE- FIXED END TEST                              ORIGINAL CABLE
   7                    62.4
    5.875
      1.0
     .313
     .521
     .833
    2.667
    3.167
     .033  2.805E-3    5.52      1.0     7
4.154E-3
        3     65.0    200.0      0.0                        6
   1    4    0                                    2
   2              13.
```

TABLE 7.3 EXAMPLE I(B) – INPUT DATA FILE

SIX MASS EXAMPLE- FIXED END TEST ORIGINAL CABLE

DATE - WED, MAR 28 1984 TIME - 23:28:17

+++++++++PROGRAM RUNNING IN SINGLE PRECISION+++++++++

N O T E S O N O U T P U T D A T A

1. ALL WEIGHTS ARE TOTAL EFFECTIVE WEIGHTS AND INCLUDE EFFECTS OF ADDED WATER MASS.

2. MODE SEARCH VELOCITY LIMITS CALCULATED FROM STROUHAL'S RELATIONSHIP USE MIN. DIAMETER FOR LOWER LIMIT AND MAX. DIAMETER FOR UPPER LIMIT AND INCREMENT.

3. DRAG IS NOT CALCULATED ON SPRUNG MASSES.

4. TABULATED RESPONSE AMPLITUDES ARE ONE HALF OF THE PEAK TO PEAK RESPONSE.

5. IN THE OUTPUT DATA, AN ASTERISK (*) BESIDE A SEGMENT NO. INDICATES THAT THIS SEGMENT IS ACTIVE FOR THE PARTICULAR MODE AND FLOW VELOCITY, I.E. IT IS BEING EXCITED BY VORTEX SHEDDING.

INPUT DATA SET NO. 1

SEGMENT DEFINITION			CABLE SEGMENT DATA				ATTACHED WEIGHT DATA				SPRUNG WT DATA	
SEG NO	LENGTH (FT)	ARC LENGTH (FT)	DIAM (IN)	DRAG COEF	WT/LENGTH (LB/FT)	TENSION (LB)	ATTACHED WT (LB)	DRAG COEF	PROJ AREA (FT**2)	EFFECT DIA (IN)	ATT SPR (LB/FT)	SPRUNG WT (LB)
1	5.875	5.875	3.300E-02	1.00	2.805E-03	5.52	4.154E-03	0.00	0.000E-01	3.300E-02	0.00	0.00
2	1.000	6.875	3.300E-02	1.00	2.805E-03	5.52	4.154E-03	0.00	0.000E-01	3.300E-02	0.00	0.00
3	0.313	7.188	3.300E-02	1.00	2.805E-03	5.52	4.154E-03	0.00	0.000E-01	3.300E-02	0.00	0.00
4	0.521	7.709	3.300E-02	1.00	2.805E-03	5.52	4.154E-03	0.00	0.000E-01	3.300E-02	0.00	0.00
5	0.833	8.542	3.300E-02	1.00	2.805E-03	5.52	4.154E-03	0.00	0.000E-01	3.300E-02	0.00	0.00
6	2.667	11.209	3.300E-02	1.00	2.805E-03	5.52	4.154E-03	0.00	0.000E-01	3.300E-02	0.00	0.00
7	3.167	14.376	3.300E-02	1.00	2.805E-03	5.52	0.000E-01	0.00	0.000E-01	3.300E-02	0.00	0.00

TOTAL NO OF SEGMENTS = 7

AVERAGE CABLE DRAG COEF = 1.000 BASED ON PROJECTED CABLE AREA OF 3.953E-02 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 6 MASSES AND PROJECTED AREA OF 0.000E-01 (FT**2)

TABLE 7.4 EXAMPLE I(B) – OUTPUT DATA FILE

MAXIMUM NO OF MODES SOUGHT = 3

BOUNDARY CONDITION AT END OF LAST SEGMENT : FIXED

MODE SEARCH LIMITS

	LOWER LIMIT	UPPER LIMIT	INCREMENT
KNOTS	0.5040	1.5507	0.0011
HERTZ	65.0000	200.0000	0.1393
FT/SEC	0.8512	2.6190	0.0018
CM/SEC	25.9443	79.8286	0.0556
RAD/SEC	408.4070	1256.6370	0.8755

FRACTION OF STRUCTURAL CRITICAL DAMPING IN AIR = 0.0000

FLUID DENSITY = 6.240E 01 (LB/FT*3)

FRACTION OF STRUCTURAL CRITICAL DAMPING IN FLUID = 0.0000

TABLE 7.4 (CTD.)

```
MODE NO   10

FREQUENCY =  4.219E 02 RAD/SEC    AVERAGE STROUHAL VELOCITY  8.794E-01 FT/SEC
          =  6.715E 01 HERTZ          BASED ON DIAMETER      2.680E 01 CM/SEC
                                      OF  3.300E-02 IN.      5.207E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING =  0.000E-01   EFFECTIVE MASS PARAMETER =  8.621E 00

MAX DISPLACEMENT =  4.105E-02  OCCURING IN SEGMENT NUMBER   1

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) =    -0.000 %

AVERAGE CABLE DRAG COEF =      1.833 BASED ON PROJECTED CABLE AREA OF  3.953E-02 (FT**2)

AVERAGE MASS DRAG COEF  =      0.000 OVER   6 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) =   83.305%

** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----
MODE NO   11

FREQUENCY =  5.209E 02 RAD/SEC    AVERAGE STROUHAL VELOCITY  1.086E 00 FT/SEC
          =  8.290E 01 HERTZ          BASED ON DIAMETER      3.309E 01 CM/SEC
                                      OF  3.300E-02 IN.      6.428E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING =  0.000E-01   EFFECTIVE MASS PARAMETER =  8.157E 00

MAX DISPLACEMENT =  4.101E-02  OCCURING IN SEGMENT NUMBER   7

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) =    -0.000 %

AVERAGE CABLE DRAG COEF =      1.556 BASED ON PROJECTED CABLE AREA OF  3.953E-02 (FT**2)

AVERAGE MASS DRAG COEF  =      0.000 OVER   6 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) =   55.633%

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TABLE 7.4 (CTD.)

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MODE NO   12

FREQUENCY =  5.405E 02 RAD/SEC     AVERAGE STROUHAL VELOCITY  1.127E 00 FT/SEC
          =  8.603E 01 HERTZ           BASED ON DIAMETER      3.434E 01 CM/SEC
                                       OF  3.300E-02 IN.      6.670E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING =  0.000E-01   EFFECTIVE MASS PARAMETER =  1.340E 01

MAX DISPLACEMENT =  4.130E-02  OCCURING IN SEGMENT NUMBER   3

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) =     0.003 %

AVERAGE CABLE DRAG COEF =     1.940 BASED ON PROJECTED CABLE AREA OF  3.953E-02 (FT**2)

AVERAGE MASS DRAG COEF  =     0.000 OVER   6 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) =   94.048%

** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----
```

TABLE 7.4 (CTD.)

```
SIX MASS EXAMPLE- FIXED END TEST                    ORIGINAL CABLE
  1
 NSEG     NPLOT      PLEN      NCOUNT
   7        2        13.          3
   I       CL(I)           S(I)           D(I)          ALP(I)          AW(I)
   1     5.875E 00      5.875E 00      3.300E-02      3.973E-03      4.154E-03
   2     1.000E 00      6.875E 00      3.300E-02      3.973E-03      4.154E-03
   3     3.130E-01      7.188E 00      3.300E-02      3.973E-03      4.154E-03
   4     5.210E-01      7.709E 00      3.300E-02      3.973E-03      4.154E-03
   5     8.330E-01      8.542E 00      3.300E-02      3.973E-03      4.154E-03
   6     2.667E 00      1.121E 01      3.300E-02      3.973E-03      4.154E-03
   7     3.167E 00      1.438E 01      3.300E-02      3.973E-03      0.000E-01

 MODE NO =    10      FREQUENCY =      4.219E 02NO. ITERATIONS =    3
  IPSTRT          IPSTOP
   0                0
   I      PHAS(I)         AMPL(I)         A(I)           B(I)          NZX(I)
   1     1.571E 00      1.000E 00      1.000E 00      0.000E-01        3
   2     2.890E 00      4.232E-01      1.052E-01     -4.099E-01        1
   3     1.992E-01      1.507E-01      2.983E-02      1.477E-01        0
   4    -1.230E 00      4.272E-01     -4.027E-01      1.428E-01        1
   5     2.476E 00      2.757E-01      1.702E-01     -2.169E-01        1
   6    -5.487E-01      1.523E-01     -7.945E-02      1.300E-01        2
   7     5.959E-01      5.552E-02      3.116E-02      4.595E-02        2
                                      -2.500E-06
   1
 EXCITED DIAMETER =  3.300E-02
   I      RAMP(I)         SEGSIR(I)       A(I+1)
   1     4.105E-02      4.105E-02      1.683E-02
   2     1.737E-02      1.683E-02      6.065E-03
   3     6.188E-03      6.188E-03      5.863E-03
   4     1.754E-02      8.904E-03      8.904E-03
   5     1.132E-02      8.904E-03      5.336E-03
   6     6.254E-03      6.254E-03      1.887E-03
   7     2.279E-03      2.279E-03      1.026E-07

 MODE NO =    11      FREQUENCY =      5.209E 02NO. ITERATIONS =    2
  IPSTRT          IPSTOP
   1                7
   I      PHAS(I)         AMPL(I)         A(I)           B(I)          NZX(I)
   1     1.571E 00      1.000E 00      1.000E 00      0.000E-01        3
   2     1.755E 00      2.173E 00      2.137E 00     -3.978E-01        1
   3    -1.284E 00      7.304E 00     -7.006E 00      2.067E 00        1
   4     2.749E 00      2.791E 00      1.069E 00     -2.579E 00        0
   5     1.647E 00      3.641E 00      3.630E 00     -2.782E-01        1
```

TABLE 7.5 EXAMPLE I(B) – AUXILIARY DATA FILE

6	-1.263E 00	1.197E 01	-1.140E 01	3.630E 00	2
7	-1.300E 00	3.936E 01	-3.793E 01	1.051E 01	3
			-1.635E-04		

1

EXCITED DIAMETER = 3.300E-02

I	RAMP(I)	SEGSIR(I)	A(I+1)
1	1.042E-03	1.042E-03	4.145E-04
2	2.265E-03	2.265E-03	2.154E-03
3	7.611E-03	2.687E-03	2.687E-03
4	2.909E-03	2.687E-03	2.899E-04
5	3.794E-03	3.794E-03	3.783E-03
6	1.247E-02	1.247E-02	1.095E-02
7	4.101E-02	4.101E-02	1.704E-07

MODE NO = 12 FREQUENCY = 5.405E 02NO. ITERATIONS = 1

IPSTRT IPSTOP

1 7

I	PHAS(I)	AMPL(I)	A(I)	B(I)	NZX(I)
1	1.571E 00	1.000E 00	1.000E 00	0.000E-01	4
2	1.513E 00	8.441E-01	8.427E-01	4.909E-02	0
3	-1.321E 00	2.748E 00	-2.662E 00	6.797E-01	1
4	2.380E 00	1.555E 00	1.073E 00	-1.126E 00	1
5	-5.270E-02	4.743E-01	-2.498E-02	4.737E-01	1
6	-2.740E 00	1.378E-01	-5.384E-02	-1.268E-01	2
7	2.088E 00	1.603E-01	1.393E-01	-7.925E-02	3
			3.435E-05		

1

EXCITED DIAMETER = 3.300E-02

I	RAMP(I)	SEGSIR(I)	A(I+1)
1	3.669E-02	3.669E-02	1.801E-03
2	3.097E-02	3.097E-02	2.494E-02
3	1.008E-01	4.130E-02	4.130E-02
4	5.707E-02	4.130E-02	1.738E-02
5	1.740E-02	1.738E-02	4.653E-03
6	5.055E-03	5.055E-03	2.908E-03
7	5.882E-03	5.882E-03	1.261E-06

TABLE 7.5 (CTD.)

FIGURE 7.4 EXAMPLE I(B) – PLOTTED OUTPUT

RESPONSE AMPLITUDE VS DIST ALONG CABLE

SIX MASS EXAMPLE- FIXED END TEST ORIGINAL CABLE

MODE NO.=10 FREQUENCY=67.1508HZ. SHED. DIAM=0.0330 IN. STR VEL=0.5207 KTS.

PLOT RANGE: SEGMENTS 1 TO 7

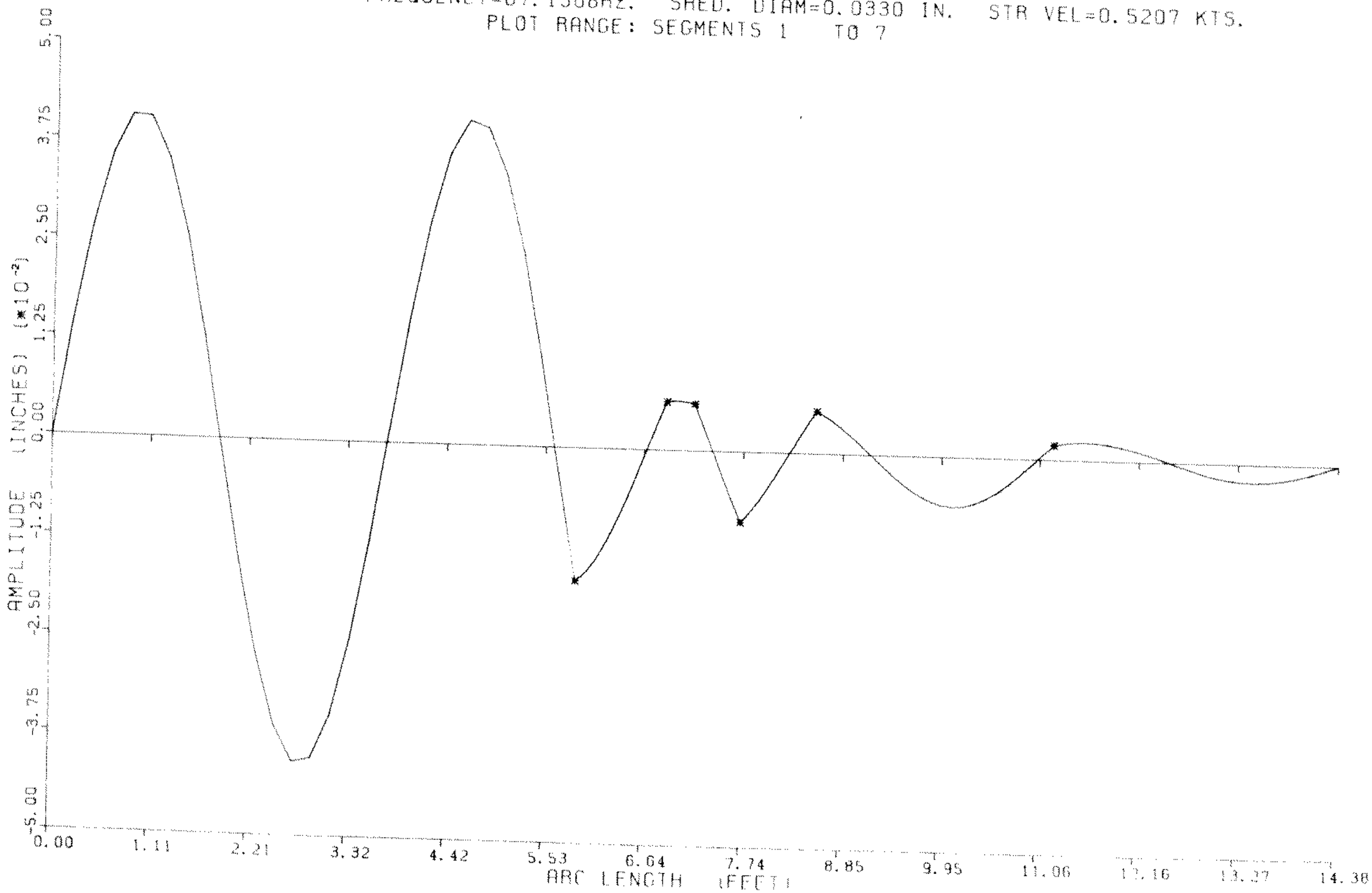


FIGURE 7.4 (CTD.)

RESPONSE AMPLITUDE VS DIST ALONG CABLE
SIX MASS EXAMPLE - FIXED END TEST ORIGINAL CABLE
MODE NO.=11 FREQUENCY=82.9045HZ. SHED. DIAM=0.0330 IN. STR VEL=0.6428 KTS.
PLOT RANGE: SEGMENTS 1 TO 7

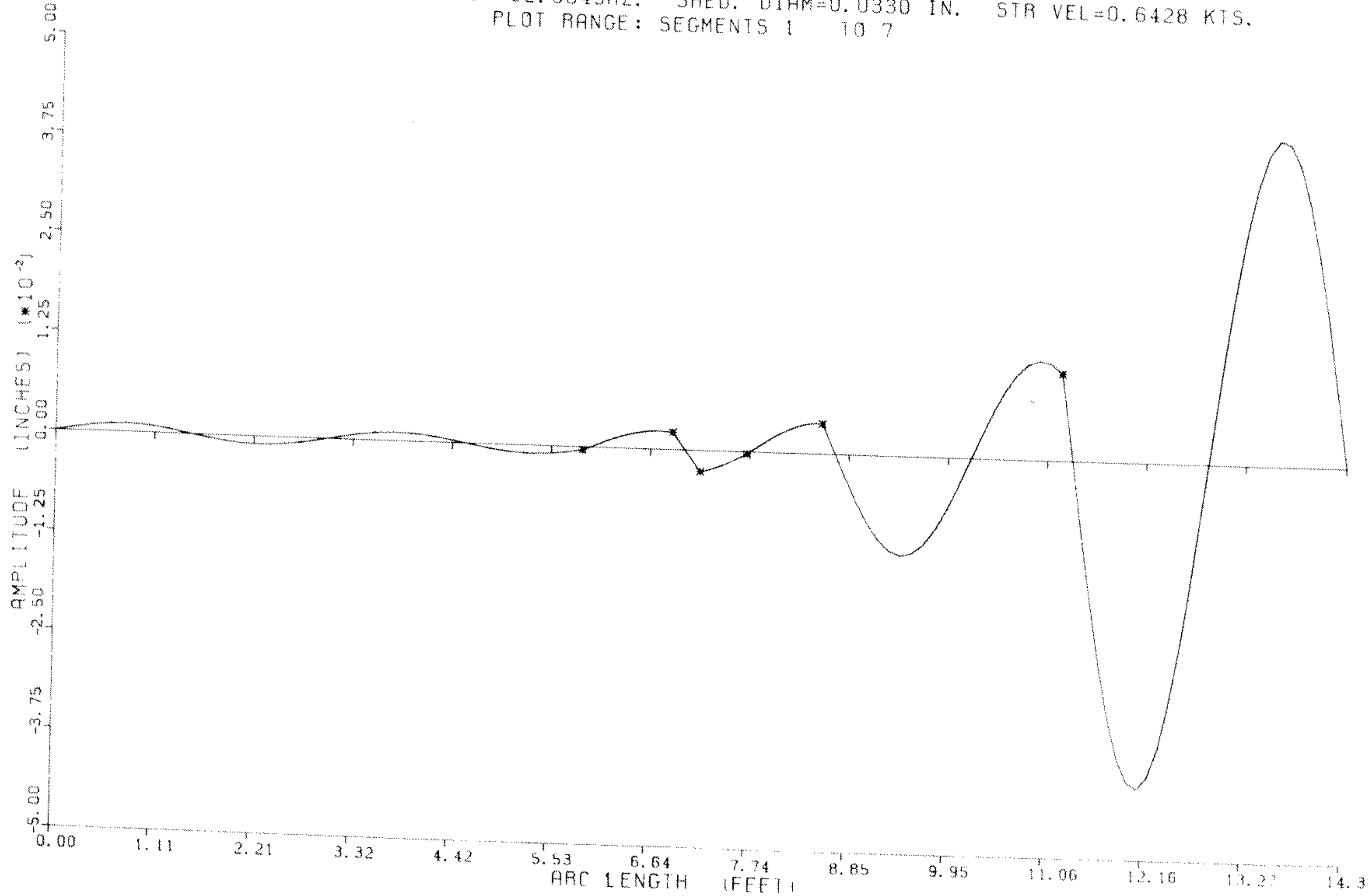
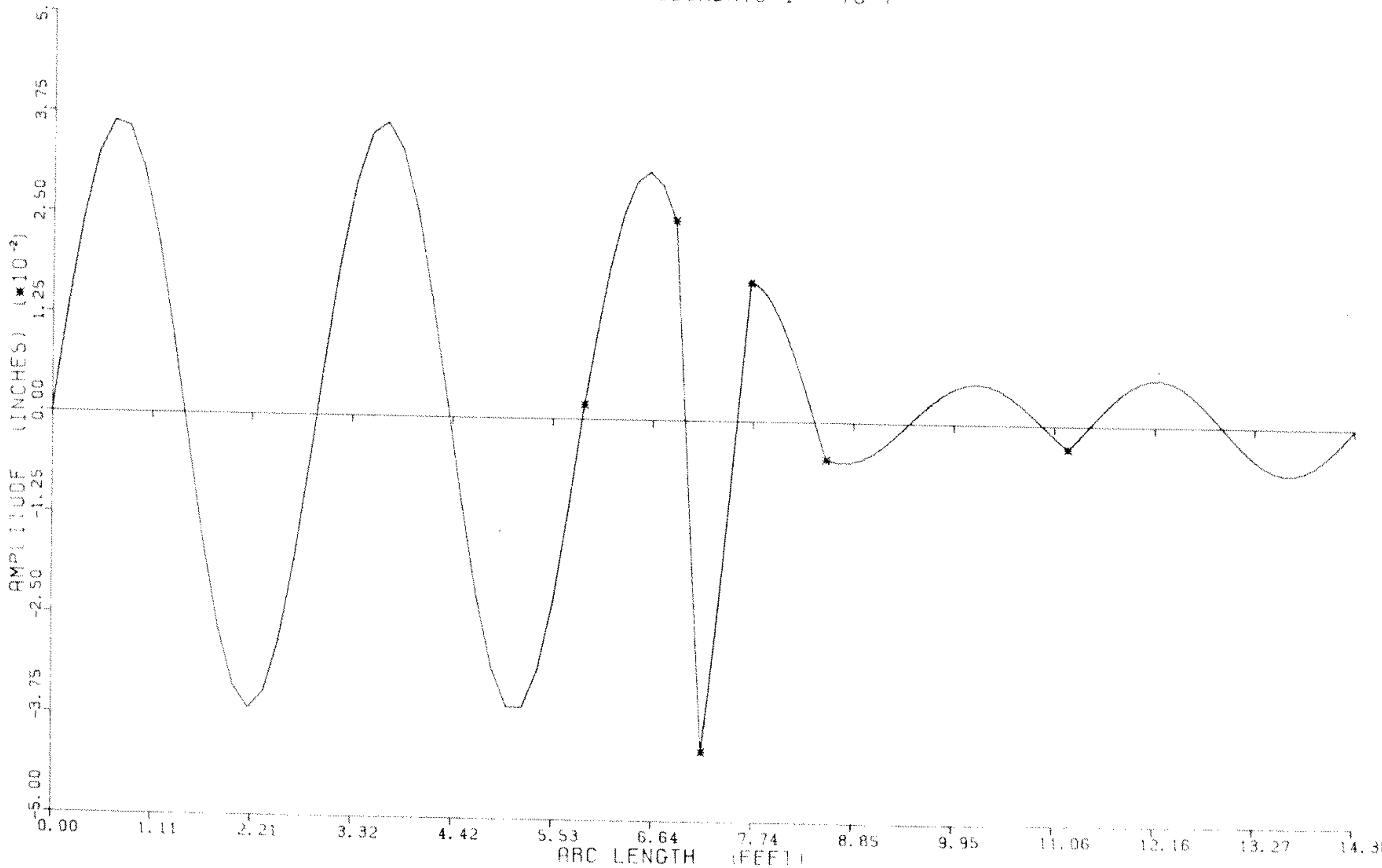


FIGURE 7.4 (CTD.)

RESPONSE AMPLITUDE VS DIST ALONG CABLE
SIX MASS EXAMPLE- FIXED END TEST ORIGINAL CABLE
MODE NO.=12 FREQUENCY=86.0294HZ. SHED. DIAM=0.0330 IN. STR VEL=0.6670 KTS.
PLOT RANGE: SEGMENTS 1 TO 7



```
SIX MASS EXAMPLE- FIXED END TEST                    ORIGINAL CABLE
  1
NSEG    NPLOT    PLEN    NCOUNT
  7       1       0.       3
  I     CL(I)        S(I)         D(I)        ALP(I)       AW(I)
  1   5.875E 00    5.875E 00   3.300E-02   3.973E-03   4.154E-03
  2   1.000E 00    6.875E 00   3.300E-02   3.973E-03   4.154E-03
  3   3.130E-01    7.188E 00   3.300E-02   3.973E-03   4.154E-03
  4   5.210E-01    7.709E 00   3.300E-02   3.973E-03   4.154E-03
  5   8.330E-01    8.542E 00   3.300E-02   3.973E-03   4.154E-03
  6   2.667E 00    1.121E 01   3.300E-02   3.973E-03   4.154E-03
  7   3.167E 00    1.438E 01   3.300E-02   3.973E-03   0.000E-01

MODE NO =   10      FREQUENCY =    4.219E 02NO. ITERATIONS =   3
 IPSTRT          IPSTOP
  2                6
  I     PHAS(I)      AMPL(I)       A(I)         B(I)       NZX(I)
  1    1.571E 00   1.000E 00    1.000E 00    0.000E-01      3
  2    2.890E 00   4.232E-01    1.052E-01   -4.099E-01      1
  3    1.992E-01   1.507E-01    2.983E-02    1.477E-01      0
  4   -1.230E 00   4.272E-01   -4.027E-01    1.428E-01      1
  5    2.476E 00   2.757E-01    1.702E-01   -2.169E-01      1
  6   -5.487E-01   1.523E-01   -7.945E-02    1.300E-01      2
  7    5.959E-01   5.552E-02    3.116E-02    4.595E-02      2
                               -2.500E-06
  1
EXCITED DIAMETER =  3.300E-02
  I     RAMP(I)      SEGSIR(I)     A(I+1)
  1    4.105E-02   4.105E-02    1.683E-02
  2    1.737E-02   1.683E-02    6.065E-03
  3    6.188E-03   6.188E-03    5.863E-03
  4    1.754E-02   8.904E-03    8.904E-03
  5    1.132E-02   8.904E-03    5.336E-03
  6    6.254E-03   6.254E-03    1.887E-03
  7    2.279E-03   2.279E-03    1.026E-07

MODE NO =   11      FREQUENCY =    5.209E 02NO. ITERATIONS =   2
 IPSTRT          IPSTOP
  3                5
  I     PHAS(I)      AMPL(I)       A(I)         B(I)       NZX(I)
  1    1.571E 00   1.000E 00    1.000E 00    0.000E-01      3
  2    1.755E 00   2.173E 00    2.137E 00   -3.978E-01      1
  3   -1.284E 00   7.304E 00   -7.006E 00    2.067E 00      1
  4    2.749E 00   2.791E 00    1.069E 00   -2.579E 00      0
  5    1.647E 00   3.641E 00    3.630E 00   -2.782E-01      1
```

TABLE 7.6 EXAMPLE I(C) – MODIFIED AUXILIARY DATA FILE

6	-1.263E 00	1.197E 01	-1.140E 01	3.630E 00	2
7	-1.300E 00	3.936E 01	-3.793E 01	1.051E 01	3
			-1.635E-04		

1
EXCITED DIAMETER = 3.300E-02

I	RAMP(I)	SEGSIR(I)	A(I+1)
1	1.042E-03	1.042E-03	4.145E-04
2	2.265E-03	2.265E-03	2.154E-03
3	7.611E-03	2.687E-03	2.687E-03
4	2.909E-03	2.687E-03	2.899E-04
5	3.794E-03	3.794E-03	3.783E-03
6	1.247E-02	1.247E-02	1.095E-02
7	4.101E-02	4.101E-02	1.704E-07

MODE NO = 12 FREQUENCY = 5.405E 02NO. ITERATIONS = 1
IPSTRT IPSTOP
2 5

I	PHAS(I)	AMPL(I)	A(I)	B(I)	NZX(I)
1	1.571E 00	1.000E 00	1.000E 00	0.000E-01	4
2	1.513E 00	8.441E-01	8.427E-01	4.909E-02	0
3	-1.321E 00	2.748E 00	-2.662E 00	6.797E-01	1
4	2.380E 00	1.555E 00	1.073E 00	-1.126E 00	1
5	-5.270E-02	4.743E-01	-2.498E-02	4.737E-01	1
6	-2.740E 00	1.378E-01	-5.384E-02	-1.268E-01	2
7	2.088E 00	1.603E-01	1.393E-01	-7.925E-02	3
			3.435E-05		

1
EXCITED DIAMETER = 3.300E-02

I	RAMP(I)	SEGSIR(I)	A(I+1)
1	3.669E-02	3.669E-02	1.801E-03
2	3.097E-02	3.097E-02	2.494E-02
3	1.008E-01	4.130E-02	4.130E-02
4	5.707E-02	4.130E-02	1.738E-02
5	1.740E-02	1.738E-02	4.653E-03
6	5.055E-03	5.055E-03	2.908E-03
7	5.882E-03	5.882E-03	1.261E-06

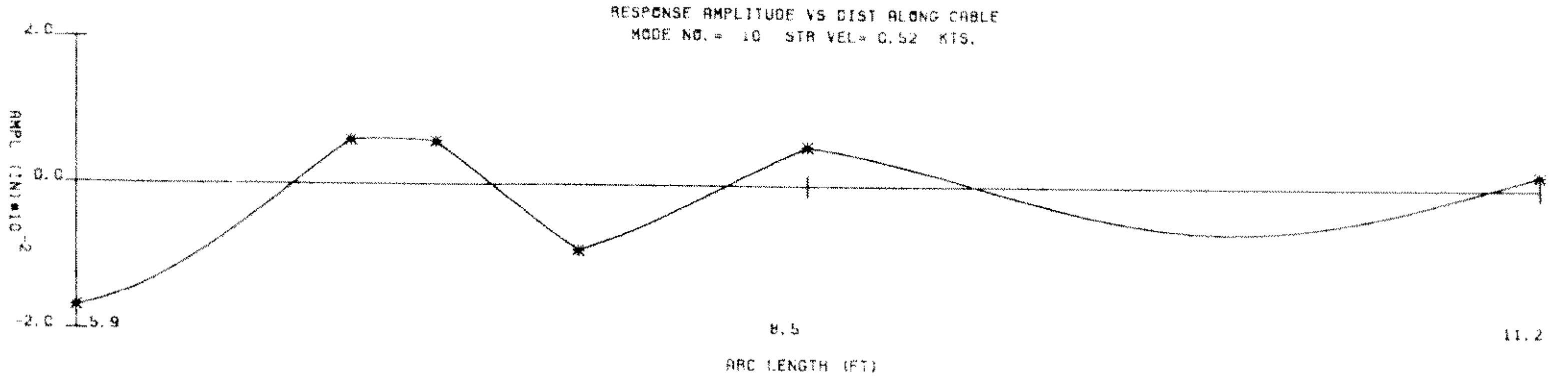
TABLE 7.6 (CTD.)

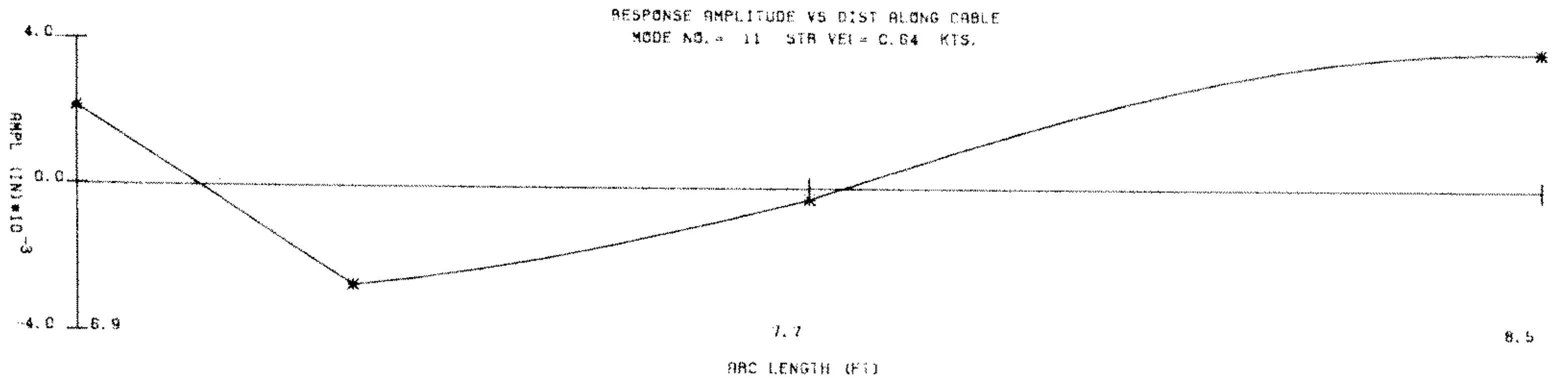
FIGURE 7.5 EXAMPLE I(C) – PLOTTED OUTPUT

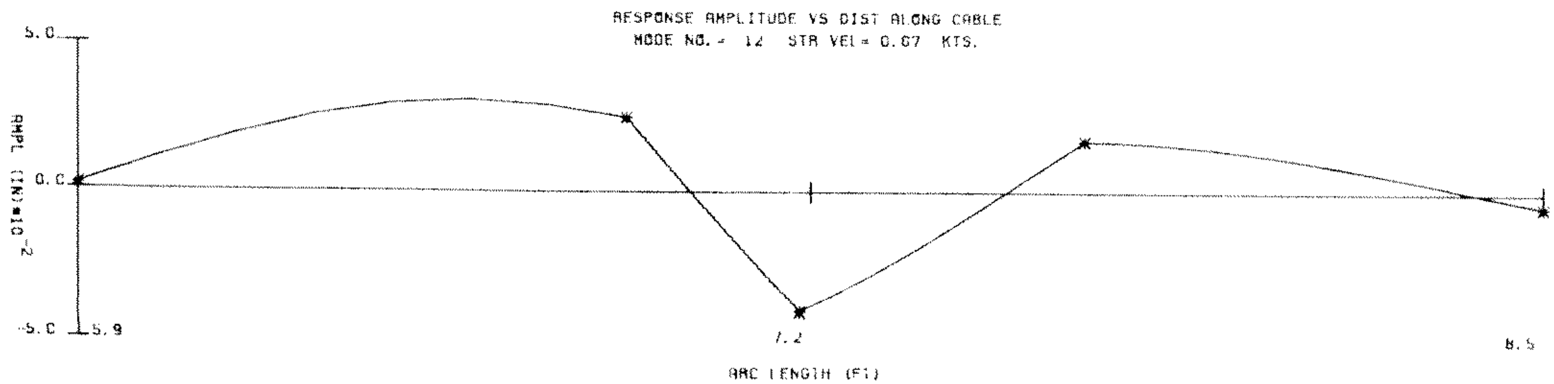
TITLE PAGE

SIX MASS EXAMPLE – FIXED END TEST
ORIGINAL CABLE

FIGURE 7.5 (CTD.)



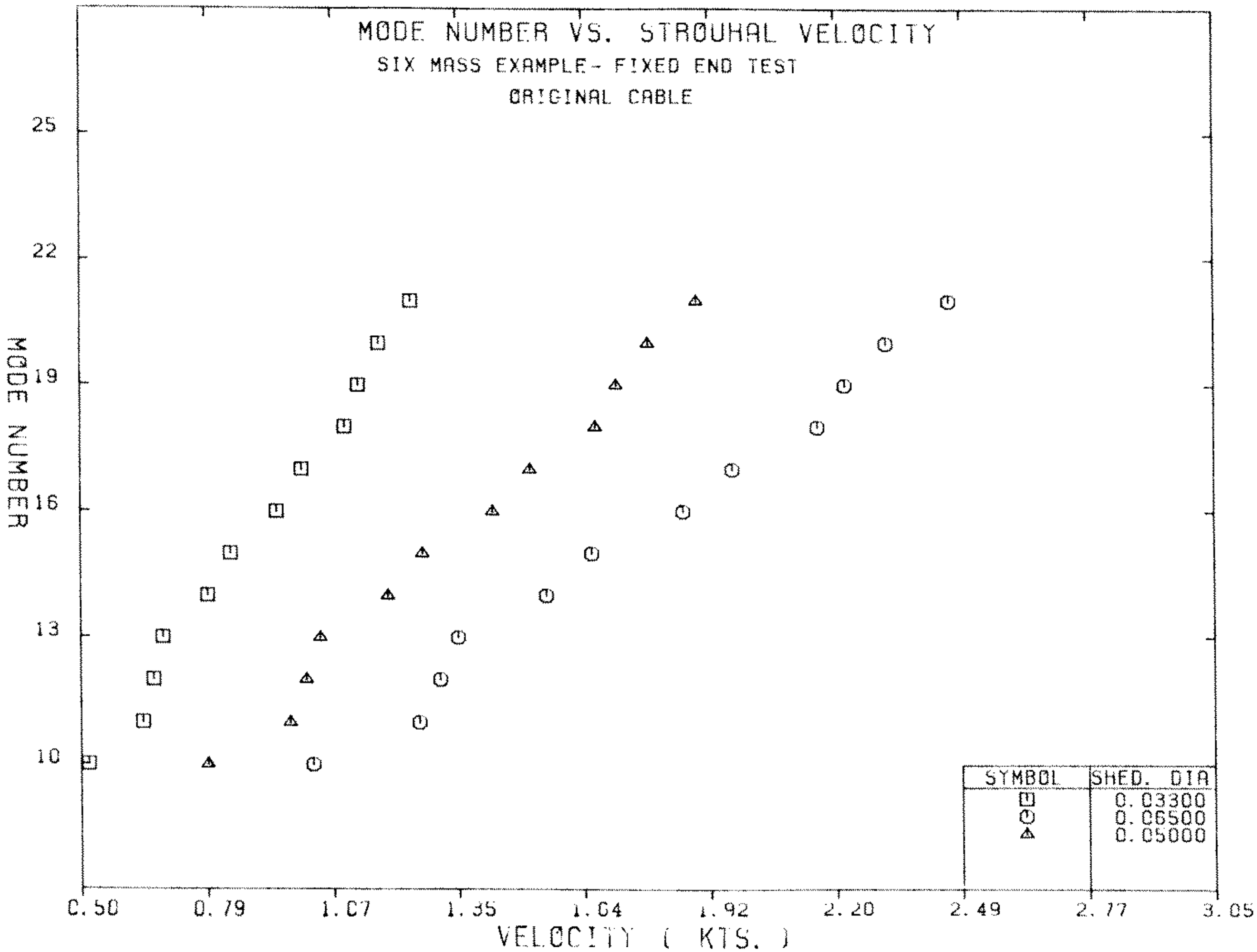




```
SIX MASS EXAMPLE- FIXED END TEST                    ORIGINAL CABLE
   7                      62.4
    5.875
      1.0
     .313
     .521
     .833
    2.667
    3.167
     .033  2.805E-3      5.52            3
     .065  2.805E-3      5.52            2
     .050  2.805E-3      5.52            2
 4.154E-3
      12     65.0      200.0      0.0    5.0E-6    2        6
  0    0    0
  5
```

TABLE 7.7 EXAMPLE I(D) – INPUT DATA FILE

FIGURE 7.6 EXAMPLE I (D) – MODE VS. VELOCITY PLOT



7.2 Example 2

The second example illustrates the use of the free end boundary condition option, and also checks the algorithm against analytically derived results. The configuration of the system is shown in Figure 7.7.

7.2.1 Example 2(a)

First, a uniform, four segment cable with no attached masses and a free end condition (right hand end) was run from the data file in Table 7.9. The standard output file (full output, no specified locations) is listed in Table 7.10 for the first five modes of the system. The ADF generated and "Pagplt" and mode vs. velocity plots produced follow in Table 7.11 and on Figures 7.8 and 7.9 respectively.

It is observed that the maximum segment response parameter in the outputs tends to a constant value in the higher modes. This behavior may be expected for a uniform cable with no attached masses (see Section 2.3 for further discussion).

7.2.2 Example 2(b)

The example was re-run with a mass of 7.0 lb added at the end of the cable assembly (see Table 7.12). The effect of the mass on the mode shapes and frequencies is clearly seen in the outputs and plots (Tables 7.13 and 7.14, Figures 7.10 and 7.11).

7.2.3 Analytical Results

Analytical results are easily found for these two cases by solving the differential equation (2-1) for the cable, assuming one segment. By satisfying the appropriate boundary conditions, the expression for the natural frequencies of the system is found from

$$\cos\alpha\omega L = 0 \tag{7-1}$$

where α and ω are defined as in Chapter 2. L is the total cable length. Solving (7-1) yields

$$\omega = \frac{1}{\alpha L}\,\frac{2n+1}{2}\,\pi \;; \quad n = \ldots -2,-1,0,1,2,\ldots \tag{7-2}$$

For the second case, with the attached mass at the end, satisfying the end boundary condition gives the following expression for ω

$$\alpha\omega L \tan\alpha\omega L = \rho L/M \tag{7-3}$$

where M is the attached weight in lbs, and ρ the weight per unit length of the cable. Although a closed form solution does not exist, the equation can be solved numerically for the modes in question. For the two cases, the frequencies found for the first five modes by evaluating (7-2) and solving (7-3) are displayed in Table 7.8.

Mode #		1	2	3	4	5
Free End	Eq (7-2)	3.443	10.33	17.22	24.10	30.99
	NATFREQ	3.444	10.33	17.22	24.11	30.99
Mass End	Eq (7-3)	1.856	7.486	14.10	20.88	27.71
	NATFREQ	1.856	7.486	14.10	20.88	27.71

Table 7.8. Natural Frequencies (rad/sec) for Free End Cable

A comparison shows good agreement between the results from NATFREQ and the above data.

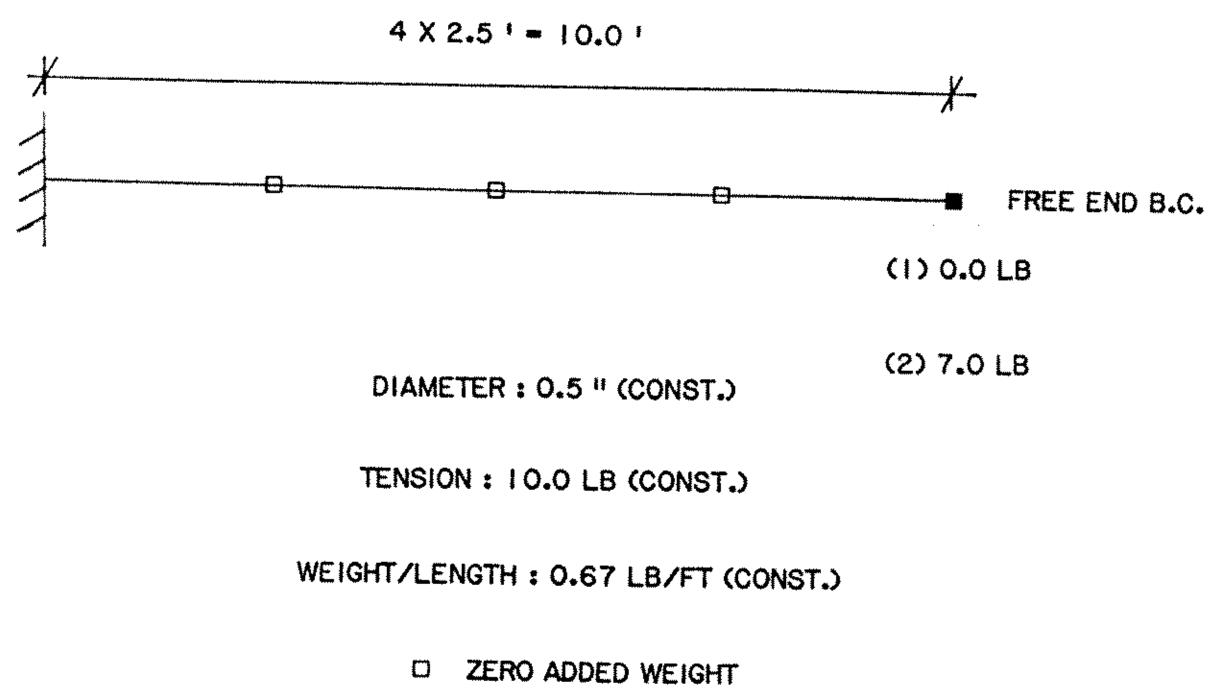


FIGURE 7.7 EXAMPLE 2(A) AND (B)

```
        FOUR SEGMENT EXAMPLE                      FREE END BOUNDARY CONDITION
0
4    1                 62.4
   2.5    4
   0.5       0.67      10.0      0.0    4
5              0.0      8.0                          4
1    2    0                                   2
3
```

TABLE 7.9 EXAMPLE 2(A) – INPUT DATA FILE

FOUR SEGMENT EXAMPLE FREE END BOUNDARY CONDITION

DATE - THU, MAR 29 1984 TIME - 09:40:31

+++++++++PROGRAM RUNNING IN SINGLE PRECISION+++++++++

N O T E S   O N   O U T P U T   D A T A

1. ALL WEIGHTS ARE TOTAL EFFECTIVE WEIGHTS AND INCLUDE EFFECTS OF ADDED WATER MASS.

2. MODE SEARCH VELOCITY LIMITS CALCULATED FROM STROUHAL'S RELATIONSHIP USE MIN. DIAMETER FOR LOWER LIMIT AND MAX. DIAMETER FOR UPPER LIMIT AND INCREMENT.

3. DRAG IS NOT CALCULATED ON SPRUNG MASSES.

4. TABULATED RESPONSE AMPLITUDES ARE ONE HALF OF THE PEAK TO PEAK RESPONSE.

5. IN THE OUTPUT DATA, AN ASTERISK (*) BESIDE A SEGMENT NO. INDICATES THAT THIS SEGMENT IS ACTIVE FOR THE PARTICULAR MODE AND FLOW VELOCITY, I.E. IT IS BEING EXCITED BY VORTEX SHEDDING.

INPUT DATA SET NO. 1

SEGMENT DEFINITION			CABLE SEGMENT DATA				ATTACHED WEIGHT DATA				SPRUNG WT DATA	
SEG NO	LENGTH (FT)	ARC LENGTH (FT)	DIAM (IN)	DRAG COEF	WT/LENGTH (LB/FT)	TENSION (LB)	ATTACHED WT (LB)	DRAG COEF	PROJ AREA (FT**2)	EFFECT DIA (IN)	ATT SPR (LB/FT)	SPRUNG WT (LB)
1	2.500	2.500	5.000E-01	0.00	6.700E-01	10.00	0.000E-01	0.00	0.000E-01	5.000E-01	0.00	0.00
2	2.500	5.000	5.000E-01	0.00	6.700E-01	10.00	0.000E-01	0.00	0.000E-01	5.000E-01	0.00	0.00
3	2.500	7.500	5.000E-01	0.00	6.700E-01	10.00	0.000E-01	0.00	0.000E-01	5.000E-01	0.00	0.00
4	2.500	10.000	5.000E-01	0.00	6.700E-01	10.00	0.000E-01	0.00	0.000E-01	5.000E-01	0.00	0.00

TOTAL NO OF SEGMENTS = 4

AVERAGE CABLE DRAG COEF = 0.000 BASED ON PROJECTED CABLE AREA OF 4.167E-01 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 0 MASSES AND PROJECTED AREA OF 0.000E-01 (FT**2)

MAXIMUM NO OF MODES SOUGHT = 5

BOUNDARY CONDITION AT END OF LAST SEGMENT : FREE

TABLE 7.10 EXAMPLE 2(A) – OUTPUT DATA FILE

MODE SEARCH LIMITS

	LOWER LIMIT	UPPER LIMIT	INCREMENT
KNOTS	0.0000	0.9398	0.0020
HERTZ	0.0000	8.0000	0.0174
FT/SEC	0.0000	1.5873	0.0035
CM/SEC	0.0000	48.3810	0.1055
RAD/SEC	0.0000	50.2655	0.1096

FRACTION OF STRUCTURAL CRITICAL DAMPING IN AIR = 0.0000

FLUID DENSITY = 6.240E 01 (LB/FT*3)

FRACTION OF STRUCTURAL CRITICAL DAMPING IN FLUID = 0.0000

TABLE 7.10 (CTD.)

```
MODE NO    1

FREQUENCY =  3.444E 00 RAD/SEC    AVERAGE STROUHAL VELOCITY  1.087E-01 FT/SEC
          =  5.481E-01 HERTZ             BASED ON DIAMETER     3.314E 00 CM/SEC
                                         OF  5.000E-01 IN.     6.439E-02 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING =  0.000E-01   EFFECTIVE MASS PARAMETER =  7.874E 00

MAX DISPLACEMENT =  5.774E-01  OCCURING IN SEGMENT NUMBER   4

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) =    -0.000 %

        CABLE RESPONSE                  MASS RESPONSE

SEGMENT    MAX SEG    DRAG COEF   MASS RESP   DRAG COEF   SPRING MASS
  NO      AMPL (IN)               AMPL (IN)   ATT WTS.   NAT FREQ (HZ)
   1 *    2.209E-01    0.000      2.209E-01    0.000        0.000
   2 *    4.082E-01    0.000      4.082E-01    0.000        0.000
   3 *    5.334E-01    0.000      5.334E-01    0.000        0.000
   4 *    5.774E-01    0.000      5.774E-01    0.000        0.000

AVERAGE CABLE DRAG COEF =      0.000 BASED ON PROJECTED CABLE AREA OF  4.167E-01 (FT**2)

AVERAGE MASS DRAG COEF  =      0.000 OVER   0 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) =    0.000%

** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----

MODE NO    2

FREQUENCY =  1.033E 01 RAD/SEC    AVERAGE STROUHAL VELOCITY  3.262E-01 FT/SEC
          =  1.644E 00 HERTZ             BASED ON DIAMETER     9.943E 00 CM/SEC
                                         OF  5.000E-01 IN.     1.932E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING =  0.000E-01   EFFECTIVE MASS PARAMETER =  7.874E 00

MAX DISPLACEMENT =  5.774E-01  OCCURING IN SEGMENT NUMBER   2

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) =     0.000 %
```

TABLE 7.10 (CTD.)

CABLE RESPONSE — MASS RESPONSE

SEGMENT NO	MAX SEG AMPL (IN)	DRAG COEF	MASS RESP AMPL (IN)	DRAG COEF ATT WTS.	SPRING MASS NAT FREQ (HZ)
1 *	5.334E-01	0.000	5.334E-01	0.000	0.000
2 *	5.774E-01	0.000	4.082E-01	0.000	0.000
3 *	4.082E-01	0.000	2.209E-01	0.000	0.000
4 *	5.774E-01	0.000	5.774E-01	0.000	0.000

AVERAGE CABLE DRAG COEF = 0.000 BASED ON PROJECTED CABLE AREA OF 4.167E-01 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 0 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) = 0.000%

** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----

MODE NO 3

FREQUENCY = 1.722E 01 RAD/SEC
= 2.740E 00 HERTZ

AVERAGE STROUHAL VELOCITY BASED ON DIAMETER OF 5.000E-01 IN. 5.437E-01 FT/SEC
1.657E 01 CM/SEC
3.219E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING = 0.000E-01 EFFECTIVE MASS PARAMETER = 7.874E 00

MAX DISPLACEMENT = 5.774E-01 OCCURING IN SEGMENT NUMBER 1

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) = -0.000 %

CABLE RESPONSE — MASS RESPONSE

SEGMENT NO	MAX SEG AMPL (IN)	DRAG COEF	MASS RESP AMPL (IN)	DRAG COEF ATT WTS.	SPRING MASS NAT FREQ (HZ)
1 *	5.774E-01	0.000	5.334E-01	0.000	0.000
2 *	5.334E-01	0.000	4.082E-01	0.000	0.000
3 *	5.774E-01	0.000	2.209E-01	0.000	0.000
4 *	5.774E-01	0.000	5.774E-01	0.000	0.000

AVERAGE CABLE DRAG COEF = 0.000 BASED ON PROJECTED CABLE AREA OF 4.167E-01 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 0 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) = 0.000%

** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----

TABLE 7.10 (CTD.)

```
MODE NO    4

FREQUENCY =  2.411E 01 RAD/SEC    AVERAGE STROUHAL VELOCITY  7.612E-01 FT/SEC
          =  3.836E 00 HERTZ           BASED ON DIAMETER      2.320E 01 CM/SEC
                                       OF  5.000E-01 IN.      4.507E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING =  0.000E-01   EFFECTIVE MASS PARAMETER =  7.874E 00

MAX DISPLACEMENT =  5.774E-01   OCCURING IN SEGMENT NUMBER   1

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) =    -0.000 %

        CABLE RESPONSE              MASS RESPONSE

SEGMENT    MAX SEG   DRAG COEF   MASS RESP  DRAG COEF   SPRING MASS
  NO      AMPL (IN)              AMPL (IN)  ATT WTS.   NAT FREQ (HZ)
   1 *    5.774E-01    0.000     2.209E-01    0.000        0.000
   2 *    5.774E-01    0.000     4.082E-01    0.000        0.000
   3 *    5.774E-01    0.000     5.334E-01    0.000        0.000
   4 *    5.774E-01    0.000     5.774E-01    0.000        0.000

AVERAGE CABLE DRAG COEF =      0.000 BASED ON PROJECTED CABLE AREA OF  4.167E-01 (FT**2)

AVERAGE MASS DRAG COEF  =      0.000 OVER   0 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) =    0.000%


** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----

MODE NO    5

FREQUENCY =  3.099E 01 RAD/SEC    AVERAGE STROUHAL VELOCITY  9.787E-01 FT/SEC
          =  4.933E 00 HERTZ           BASED ON DIAMETER      2.983E 01 CM/SEC
                                       OF  5.000E-01 IN.      5.795E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING =  0.000E-01   EFFECTIVE MASS PARAMETER =  7.874E 00

MAX DISPLACEMENT =  5.774E-01   OCCURING IN SEGMENT NUMBER   1

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) =     0.000 %
```

TABLE 7.10 (CTD.)

SEGMENT NO	CABLE RESPONSE MAX SEG AMPL (IN)	DRAG COEF	MASS RESPONSE MASS RESP AMPL (IN)	DRAG COEF ATT WTS.	SPRING MASS NAT FREQ (HZ)
1 *	5.774E-01	0.000	2.209E-01	0.000	0.000
2 *	5.774E-01	0.000	4.082E-01	0.000	0.000
3 *	5.774E-01	0.000	5.334E-01	0.000	0.000
4 *	5.774E-01	0.000	5.774E-01	0.000	0.000

AVERAGE CABLE DRAG COEF = 0.000 BASED ON PROJECTED CABLE AREA OF 4.167E-01 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 0 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) = 0.000%

** ---------- **** ---------- **** ---------- **** ---------- **** ---------- **** ---------- **** ---------- **** ---------- **** -----

TABLE 7.10 (CTD.)

```
        FOUR SEGMENT EXAMPLE                    FREE END BOUNDARY CONDITION
    1
NSEG    NPLOT     PLEN     NCOUNT
  4       3        0.        5
  I      CL(I)          S(I)          D(I)          ALP(I)        AW(I)
  1    2.500E 00     2.500E 00     5.000E-01     4.562E-02     0.000E-01
  2    2.500E 00     5.000E 00     5.000E-01     4.562E-02     0.000E-01
  3    2.500E 00     7.500E 00     5.000E-01     4.562E-02     0.000E-01
  4    2.500E 00     1.000E 01     5.000E-01     4.562E-02     0.000E-01

MODE NO =    1     FREQUENCY =     3.444E 00NO. ITERATIONS =   1
 IPSTRT        IPSTOP
  0              0
  I      PHAS(I)        AMPL(I)        A(I)          B(I)         NZX(I)
  1    1.571E 00     1.000E 00     1.000E 00     0.000E-01        0
  2    1.178E 00     1.000E 00     9.239E-01     3.827E-01        0
  3    7.854E-01     1.000E 00     7.071E-01     7.071E-01        0
  4    3.927E-01     1.000E 00     3.827E-01     9.239E-01        0
                                  -3.882E-07
  1
EXCITED DIAMETER =  5.000E-01
  I      RAMP(I)        SEGSIR(I)       A(I+1)
  1    5.774E-01     2.209E-01     2.209E-01
  2    5.774E-01     4.082E-01     4.082E-01
  3    5.774E-01     5.334E-01     5.334E-01
  4    5.774E-01     5.774E-01     5.774E-01

MODE NO =    2     FREQUENCY =     1.033E 01NO. ITERATIONS =   1
 IPSTRT        IPSTOP
  1              4
  I      PHAS(I)        AMPL(I)        A(I)          B(I)         NZX(I)
  1    1.571E 00     1.000E 00     1.000E 00     0.000E-01        0
  2    3.927E-01     1.000E 00     3.827E-01     9.239E-01        0
  3   -7.854E-01     1.000E 00    -7.071E-01     7.071E-01        1
  4   -1.963E 00     1.000E 00    -9.239E-01    -3.827E-01        0
                                   8.936E-07
  1
EXCITED DIAMETER =  5.000E-01
  I      RAMP(I)        SEGSIR(I)       A(I+1)
  1    5.774E-01     5.334E-01     5.334E-01
  2    5.774E-01     5.774E-01     4.082E-01
  3    5.774E-01     4.082E-01     2.209E-01
  4    5.774E-01     5.774E-01     5.774E-01

MODE NO =    3     FREQUENCY =     1.722E 01NO. ITERATIONS =   1
```

TABLE 7.11 EXAMPLE 2(A) – AUXILIARY DATA FILE

```
IPSTRT          IPSTOP
  1               4
  I      PHAS(I)        AMPL(I)        A(I)          B(I)         NZX(I)
  1     1.571E 00      1.000E 00     1.000E 00     0.000E-01        0
  2    -3.927E-01      1.000E 00    -3.827E-01     9.239E-01        1
  3    -2.356E 00      1.000E 00    -7.071E-01    -7.071E-01        0
  4     1.963E 00      1.000E 00     9.239E-01    -3.827E-01        1
                                    -5.859E-07
  1
EXCITED DIAMETER =  5.000E-01
  I      RAMP(I)        SEGSIR(I)      A(I+1)
  1     5.774E-01      5.774E-01     5.334E-01
  2     5.774E-01      5.334E-01     4.082E-01
  3     5.774E-01      5.774E-01     2.209E-01
  4     5.774E-01      5.774E-01     5.774E-01

MODE NO =     4     FREQUENCY =      2.411E 01NO. ITERATIONS =    1
IPSTRT          IPSTOP
  1               4
  I      PHAS(I)        AMPL(I)        A(I)          B(I)         NZX(I)
  1     1.571E 00      1.000E 00     1.000E 00     0.000E-01        0
  2    -1.178E 00      1.000E 00    -9.239E-01     3.827E-01        1
  3     2.356E 00      1.000E 00     7.071E-01    -7.071E-01        1
  4    -3.927E-01      1.000E 00    -3.827E-01     9.239E-01        1
                                    -6.308E-07
  1
EXCITED DIAMETER =  5.000E-01
  I      RAMP(I)        SEGSIR(I)      A(I+1)
  1     5.774E-01      5.774E-01     2.209E-01
  2     5.774E-01      5.774E-01     4.082E-01
  3     5.774E-01      5.774E-01     5.334E-01
  4     5.774E-01      5.774E-01     5.774E-01

MODE NO =     5     FREQUENCY =      3.099E 01NO. ITERATIONS =    1
IPSTRT          IPSTOP
  1               4
  I      PHAS(I)        AMPL(I)        A(I)          B(I)         NZX(I)
  1     1.571E 00      1.000E 00     1.000E 00     0.000E-01        1
  2    -1.963E 00      1.000E 00    -9.239E-01    -3.827E-01        1
  3     7.854E-01      1.000E 00     7.071E-01     7.071E-01        1
  4    -2.749E 00      1.000E 00    -3.827E-01    -9.239E-01        1
                                     8.826E-07
  1
EXCITED DIAMETER =  5.000E-01
  I      RAMP(I)        SEGSIR(I)      A(I+1)
```

TABLE 7.11 (CTD.)

1	5.774E-01	5.774E-01	2.209E-01
2	5.774E-01	5.774E-01	4.082E-01
3	5.774E-01	5.774E-01	5.334E-01
4	5.774E-01	5.774E-01	5.774E-01

TABLE 7.11 (CTD.)

FIGURE 7.8 EXAMPLE 2(A) – PLOTTED OUTPUT

TITLE PAGE

FØUR SEGMENT EXAMPLE
FREE END BØUNDARY CØNDITIØN

FIGURE 7.8 (CTD.)

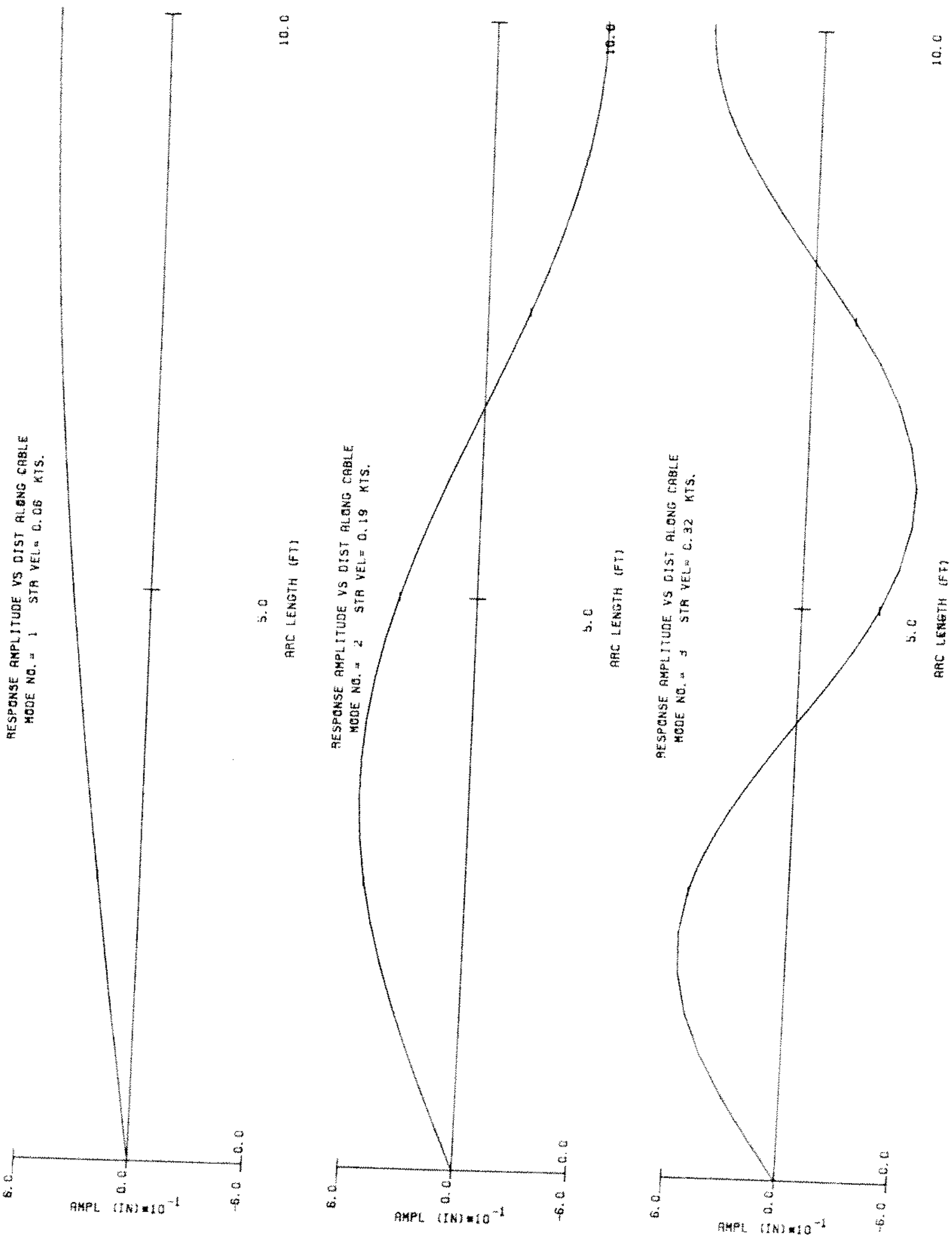
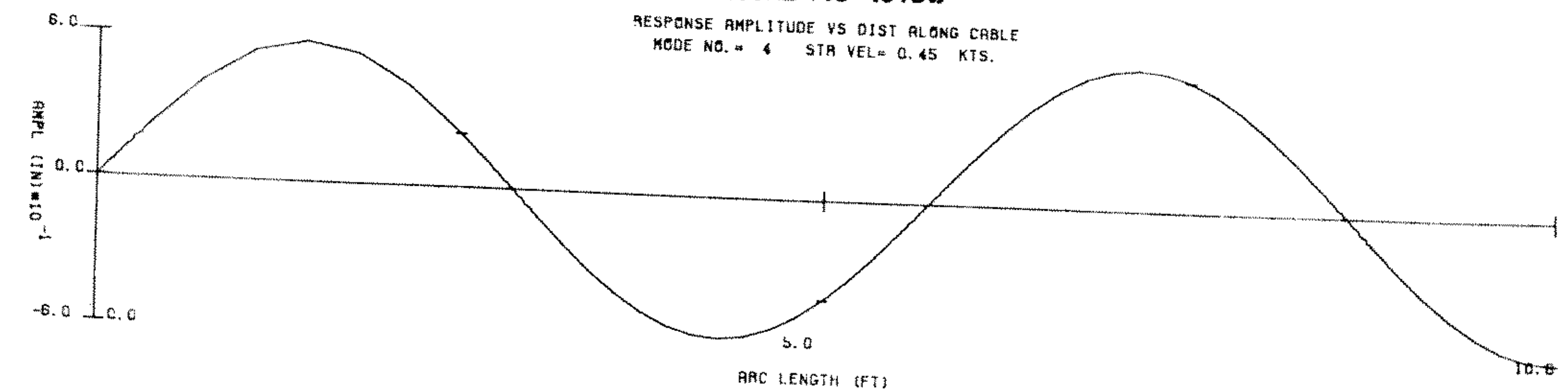


FIGURE 7.8 (CTD.)



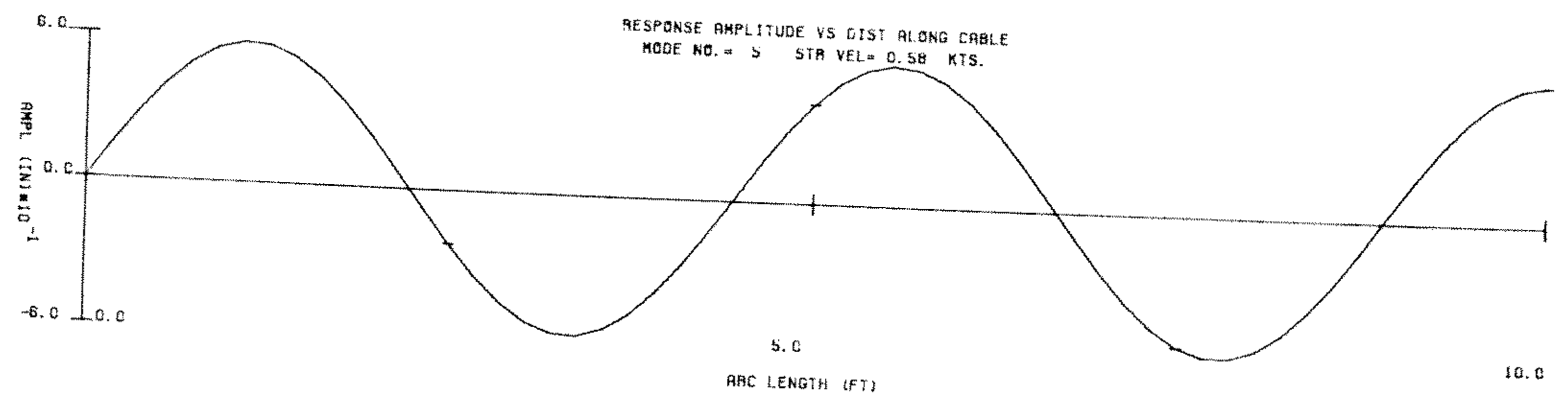
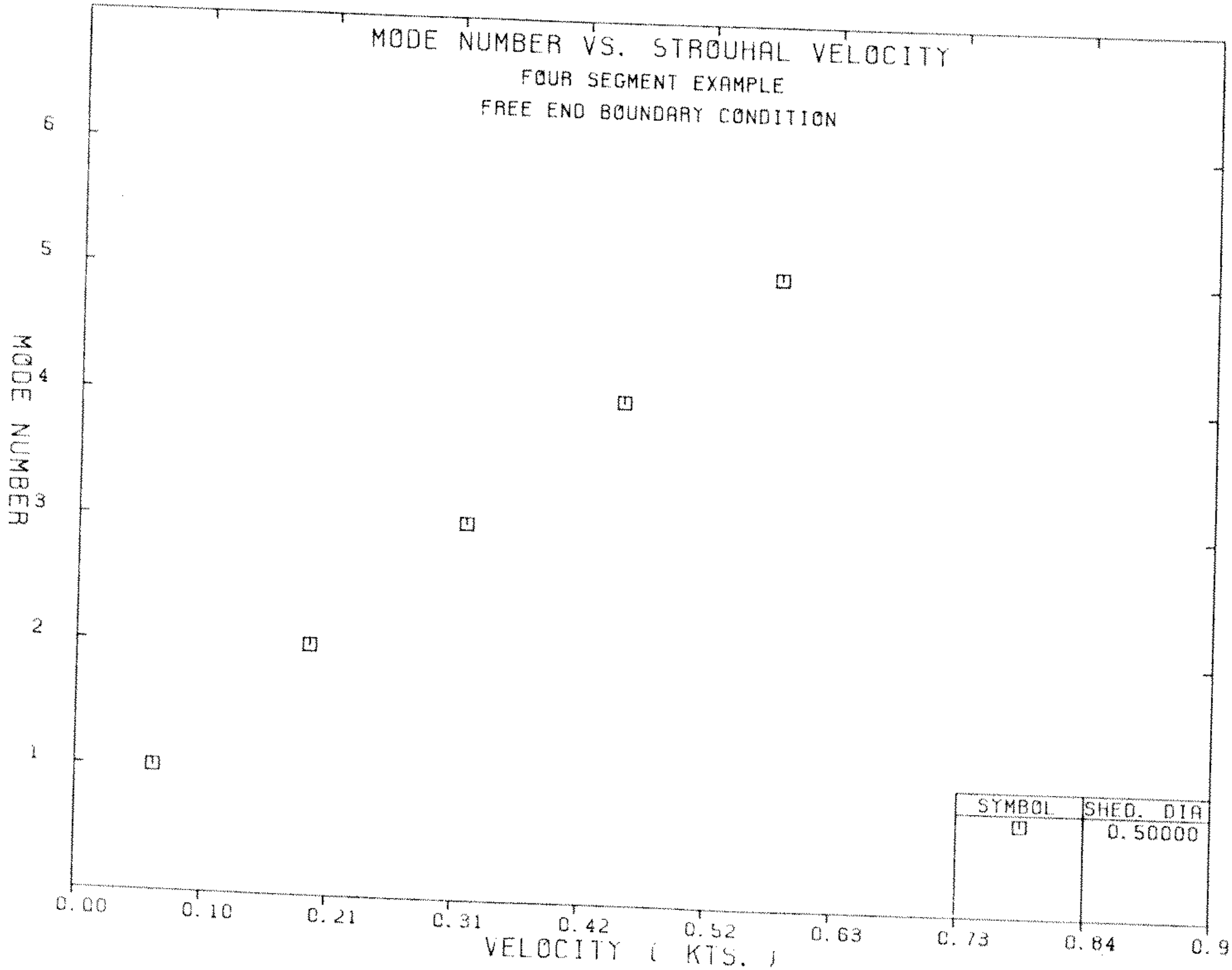


FIGURE 7.9 EXAMPLE 2(A) – MODE VS. VELOCITY PLOT



```
     FOUR SEGMENT EXAMPLE                    FREE END BOUNDARY CONDITION
0
4    1                62.4
   2.5    4
   0.5      0.67      10.0      0.0    4
                                                         3
   7.0
5            0.0       8.0
1    2    0                                      2
3
```

TABLE 7.12 EXAMPLE 2(B) – INPUT DATA FILE

FOUR SEGMENT EXAMPLE FREE END BOUNDARY CONDITION

DATE - THU, MAR 29 1984 TIME - 09:48:27

+++++++++PROGRAM RUNNING IN SINGLE PRECISION+++++++++

NOTES ON OUTPUT DATA

1. ALL WEIGHTS ARE TOTAL EFFECTIVE WEIGHTS AND INCLUDE EFFECTS OF ADDED WATER MASS.

2. MODE SEARCH VELOCITY LIMITS CALCULATED FROM STROUHAL'S RELATIONSHIP USE MIN. DIAMETER FOR LOWER LIMIT AND MAX. DIAMETER FOR UPPER LIMIT AND INCREMENT.

3. DRAG IS NOT CALCULATED ON SPRUNG MASSES.

4. TABULATED RESPONSE AMPLITUDES ARE ONE HALF OF THE PEAK TO PEAK RESPONSE.

5. IN THE OUTPUT DATA, AN ASTERISK (*) BESIDE A SEGMENT NO. INDICATES THAT THIS SEGMENT IS ACTIVE FOR THE PARTICULAR MODE AND FLOW VELOCITY, I.E. IT IS BEING EXCITED BY VORTEX SHEDDING.

INPUT DATA SET NO. 1

SEGMENT DEFINITION			CABLE SEGMENT DATA				ATTACHED WEIGHT DATA				SPRUNG WT DATA	
SEG NO	LENGTH (FT)	ARC LENGTH (FT)	DIAM (IN)	DRAG COEF	WT/LENGTH (LB/FT)	TENSION (LB)	ATTACHED WT (LB)	DRAG COEF	PROJ AREA (FT**2)	EFFECT DIA (IN)	ATT SPR (LB/FT)	SPRUNG WT (LB)
1	2.500	2.500	5.000E-01	0.00	6.700E-01	10.00	0.000E-01	0.00	0.000E-01	5.000E-01	0.00	0.00
2	2.500	5.000	5.000E-01	0.00	6.700E-01	10.00	0.000E-01	0.00	0.000E-01	5.000E-01	0.00	0.00
3	2.500	7.500	5.000E-01	0.00	6.700E-01	10.00	0.000E-01	0.00	0.000E-01	5.000E-01	0.00	0.00
4	2.500	10.000	5.000E-01	0.00	6.700E-01	10.00	7.000E 00	0.00	0.000E-01	5.000E-01	0.00	0.00

TOTAL NO OF SEGMENTS = 4

AVERAGE CABLE DRAG COEF = 0.000 BASED ON PROJECTED CABLE AREA OF 4.167E-01 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 1 MASSES AND PROJECTED AREA OF 0.000E-01 (FT**2)

MAXIMUM NO OF MODES SOUGHT = 5

BOUNDARY CONDITION AT END OF LAST SEGMENT : FREE

TABLE 7.13 EXAMPLE 2(B) – OUTPUT DATA FILE

MODE SEARCH LIMITS

	LOWER LIMIT	UPPER LIMIT	INCREMENT
KNOTS	0.0000	0.9398	0.0020
HERTZ	0.0000	8.0000	0.0171
FT/SEC	0.0000	1.5873	0.0034
CM/SEC	0.0000	48.3810	0.1032
RAD/SEC	0.0000	50.2655	0.1072

FRACTION OF STRUCTURAL CRITICAL DAMPING IN AIR = 0.0000

FLUID DENSITY = 6.240E 01 (LB/FT*3)

FRACTION OF STRUCTURAL CRITICAL DAMPING IN FLUID = 0.0000

TABLE 7.13 (CTD.)

MODE NO 1

```
FREQUENCY =  1.856E 00 RAD/SEC    AVERAGE STROUHAL VELOCITY  5.861E-02 FT/SEC
          =  2.954E-01 HERTZ           BASED ON DIAMETER      1.786E 00 CM/SEC
                                       OF  5.000E-01 IN.      3.470E-02 KNOTS
```

EFFECTIVE FLUID/STRUCTURE DAMPING = 0.000E-01 EFFECTIVE MASS PARAMETER = 3.018E 01

MAX DISPLACEMENT = 5.261E-01 OCCURING IN SEGMENT NUMBER 4

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) = 0.000 %

	CABLE RESPONSE		MASS RESPONSE		
SEGMENT NO	MAX SEG AMPL (IN)	DRAG COEF	MASS RESP AMPL (IN)	DRAG COEF ATT WTS.	SPRING MASS NAT FREQ (HZ)
1 *	1.476E-01	0.000	1.476E-01	0.000	0.000
2 *	2.885E-01	0.000	2.885E-01	0.000	0.000
3 *	4.166E-01	0.000	4.166E-01	0.000	0.000
4 *	5.261E-01	0.000	5.261E-01	0.000	0.000
					0.000

AVERAGE CABLE DRAG COEF = 0.000 BASED ON PROJECTED CABLE AREA OF 4.167E-01 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 1 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) = 0.000%

** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----

MODE NO 2

```
FREQUENCY =  7.486E 00 RAD/SEC    AVERAGE STROUHAL VELOCITY  2.364E-01 FT/SEC
          =  1.191E 00 HERTZ           BASED ON DIAMETER      7.206E 00 CM/SEC
                                       OF  5.000E-01 IN.      1.400E-01 KNOTS
```

EFFECTIVE FLUID/STRUCTURE DAMPING = 0.000E-01 EFFECTIVE MASS PARAMETER = 9.172E 00

MAX DISPLACEMENT = 6.194E-01 OCCURING IN SEGMENT NUMBER 2

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) = -0.000 %

TABLE 7.13 (CTD.)

	CABLE RESPONSE		MASS RESPONSE		
SEGMENT NO	MAX SEG AMPL (IN)	DRAG COEF	MASS RESP AMPL (IN)	DRAG COEF ATT WTS.	SPRING MASS NAT FREQ (HZ)
1 *	4.669E-01	0.000	4.669E-01	0.000	0.000
2 *	6.194E-01	0.000	6.136E-01	0.000	0.000
3 *	6.136E-01	0.000	3.397E-01	0.000	0.000
4 *	3.397E-01	0.000	1.672E-01	0.000	0.000

AVERAGE CABLE DRAG COEF = 0.000 BASED ON PROJECTED CABLE AREA OF 4.167E-01 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 1 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) = 0.000%

** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----

MODE NO 3

FREQUENCY = 1.410E 01 RAD/SEC AVERAGE STROUHAL VELOCITY 4.452E-01 FT/SEC
= 2.244E 00 HERTZ BASED ON DIAMETER 1.357E 01 CM/SEC
OF 5.000E-01 IN. 2.636E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING = 0.000E-01 EFFECTIVE MASS PARAMETER = 8.239E 00

MAX DISPLACEMENT = 5.903E-01 OCCURING IN SEGMENT NUMBER 1

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) = 0.000 %

	CABLE RESPONSE		MASS RESPONSE		
SEGMENT NO	MAX SEG AMPL (IN)	DRAG COEF	MASS RESP AMPL (IN)	DRAG COEF ATT WTS.	SPRING MASS NAT FREQ (HZ)
1 *	5.903E-01	0.000	5.899E-01	0.000	0.000
2 *	5.899E-01	0.000	4.357E-02	0.000	0.000
3 *	5.903E-01	0.000	5.867E-01	0.000	0.000
4 *	5.867E-01	0.000	8.690E-02	0.000	0.000

AVERAGE CABLE DRAG COEF = 0.000 BASED ON PROJECTED CABLE AREA OF 4.167E-01 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 1 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) = 0.000%

** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----

TABLE 7.13 (CTD.)

```
MODE NO    4

FREQUENCY =  2.088E 01 RAD/SEC     AVERAGE STROUHAL VELOCITY  6.594E-01 FT/SEC
          =  3.323E 00 HERTZ            BASED ON DIAMETER      2.010E 01 CM/SEC
                                        OF  5.000E-01 IN.      3.904E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING =  0.000E-01   EFFECTIVE MASS PARAMETER =  8.041E 00

MAX DISPLACEMENT =  5.834E-01  OCCURING IN SEGMENT NUMBER   1

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) =    -0.000 %
```

SEGMENT NO	CABLE RESPONSE: MAX SEG AMPL (IN)	CABLE RESPONSE: DRAG COEF	MASS RESPONSE: MASS RESP AMPL (IN)	MASS RESPONSE: DRAG COEF ATT WTS.	MASS RESPONSE: SPRING MASS NAT FREQ (HZ)
1 *	5.834E-01	0.000	4.020E-01	0.000	0.000
2 *	5.834E-01	0.000	5.826E-01	0.000	0.000
3 *	5.826E-01	0.000	4.423E-01	0.000	0.000
4 *	5.834E-01	0.000	5.833E-02	0.000	0.000
					0.000

```
AVERAGE CABLE DRAG COEF =     0.000 BASED ON PROJECTED CABLE AREA OF  4.167E-01 (FT**2)

AVERAGE MASS DRAG COEF  =     0.000 OVER   1 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) =    0.000%

** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----

MODE NO    5

FREQUENCY =  2.771E 01 RAD/SEC     AVERAGE STROUHAL VELOCITY  8.752E-01 FT/SEC
          =  4.411E 00 HERTZ            BASED ON DIAMETER      2.668E 01 CM/SEC
                                        OF  5.000E-01 IN.      5.182E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING =  0.000E-01   EFFECTIVE MASS PARAMETER =  7.969E 00

MAX DISPLACEMENT =  5.808E-01  OCCURING IN SEGMENT NUMBER   1

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) =    0.000 %
```

TABLE 7.13 (CTD.)

	CABLE RESPONSE		MASS RESPONSE		
SEGMENT NO	MAX SEG AMPL (IN)	DRAG COEF	MASS RESP AMPL (IN)	DRAG COEF ATT WTS.	SPRING MASS NAT FREQ (HZ)
1 *	5.808E-01	0.000	1.097E-02	0.000	0.000
2 *	5.808E-01	0.000	2.194E-02	0.000	0.000
3 *	5.808E-01	0.000	3.290E-02	0.000	0.000
4 *	5.808E-01	0.000	4.385E-02	0.000	0.000

AVERAGE CABLE DRAG COEF = 0.000 BASED ON PROJECTED CABLE AREA OF 4.167E-01 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 1 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) = 0.000%

** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----

TABLE 7.13 (CTD.)

```
            FOUR SEGMENT EXAMPLE                          FREE END BOUNDARY CONDITION
   1
 NSEG     NPLOT      PLEN      NCOUNT
   4        3         0.          5
   I       CL(I)          S(I)          D(I)          ALP(I)          AW(I)
   1     2.500E 00     2.500E 00     5.000E-01     4.562E-02     0.000E-01
   2     2.500E 00     5.000E 00     5.000E-01     4.562E-02     0.000E-01
   3     2.500E 00     7.500E 00     5.000E-01     4.562E-02     0.000E-01
   4     2.500E 00     1.000E 01     5.000E-01     4.562E-02     7.000E 00
 MODE NO =     1      FREQUENCY =      1.856E 00NO. ITERATIONS =    2
  IPSTRT           IPSTOP
   0                 0
   I      PHAS(I)        AMPL(I)         A(I)          B(I)         NZX(I)
   1     1.571E 00     1.000E 00     1.000E 00     0.000E-01        0
   2     1.359E 00     1.000E 00     9.777E-01     2.101E-01        0
   3     1.147E 00     1.000E 00     9.117E-01     4.108E-01        0
   4     9.358E-01     1.000E 00     8.051E-01     5.931E-01        0
                                     1.671E-06
   1
 EXCITED DIAMETER =   5.000E-01
   I      RAMP(I)       SEGSIR(I)       A(I+1)
   1     7.024E-01     1.476E-01     1.476E-01
   2     7.024E-01     2.885E-01     2.885E-01
   3     7.024E-01     4.166E-01     4.166E-01
   4     7.024E-01     5.261E-01     5.261E-01
 MODE NO =     2      FREQUENCY =      7.486E 00NO. ITERATIONS =    2
  IPSTRT           IPSTOP
   1                 4
   I      PHAS(I)        AMPL(I)         A(I)          B(I)         NZX(I)
   1     1.571E 00     1.000E 00     1.000E 00     0.000E-01        0
   2     7.171E-01     1.000E 00     6.572E-01     7.537E-01        0
   3    -1.366E-01     1.000E 00    -1.362E-01     9.907E-01        0
   4    -9.904E-01     1.000E 00    -8.362E-01     5.484E-01        1
                                    -4.059E-07
   1
 EXCITED DIAMETER =   5.000E-01
   I      RAMP(I)       SEGSIR(I)       A(I+1)
   1     6.194E-01     4.669E-01     4.669E-01
   2     6.194E-01     6.194E-01     6.136E-01
   3     6.194E-01     6.136E-01     3.397E-01
   4     6.194E-01     3.397E-01     1.672E-01
 MODE NO =     3      FREQUENCY =      1.410E 01NO. ITERATIONS =    2
```

TABLE 7.14 EXAMPLE 2(B) – AUXILIARY DATA FILE

```
IPSTRT        IPSTOP
  1              4
  I     PHAS(I)       AMPL(I)        A(I)          B(I)        NZX(I)
  1    1.571E 00     1.000E 00     1.000E 00     0.000E-01       0
  2   -3.694E-02     1.000E 00    -3.693E-02     9.993E-01       1
  3   -1.645E 00     1.000E 00    -9.973E-01    -7.381E-02       0
  4    3.031E 00     1.000E 00     1.106E-01    -9.939E-01       1
                                   1.048E-06
  1
EXCITED DIAMETER =  5.000E-01
  I     RAMP(I)       SEGSIR(I)      A(I+1)
  1    5.903E-01     5.903E-01     5.899E-01
  2    5.903E-01     5.899E-01     4.357E-02
  3    5.903E-01     5.903E-01     5.867E-01
  4    5.903E-01     5.867E-01     8.690E-02
MODE NO =    4    FREQUENCY =     2.088E 01NO. ITERATIONS =   2
IPSTRT        IPSTOP
  1              4
  I     PHAS(I)       AMPL(I)        A(I)          B(I)        NZX(I)
  1    1.571E 00     1.000E 00     1.000E 00     0.000E-01       0
  2   -8.104E-01     1.000E 00    -7.246E-01     6.892E-01       1
  3    3.092E 00     1.000E 00     5.006E-02    -9.987E-01       1
  4    7.103E-01     1.000E 00     6.520E-01     7.582E-01       1
                                  -3.322E-07
  1
EXCITED DIAMETER =  5.000E-01
  I     RAMP(I)       SEGSIR(I)      A(I+1)
  1    5.834E-01     5.834E-01     4.020E-01
  2    5.834E-01     5.834E-01     5.826E-01
  3    5.834E-01     5.826E-01     4.423E-01
  4    5.834E-01     5.834E-01     5.833E-02
MODE NO =    5    FREQUENCY =     2.771E 01NO. ITERATIONS =   2
IPSTRT        IPSTOP
  1              4
  I     PHAS(I)       AMPL(I)        A(I)          B(I)        NZX(I)
  1    1.571E 00     1.000E 00     1.000E 00     0.000E-01       1
  2   -1.590E 00     1.000E 00    -9.998E-01    -1.889E-02       1
  3    1.533E 00     1.000E 00     9.993E-01     3.777E-02       1
  4   -1.627E 00     1.000E 00    -9.984E-01    -5.665E-02       1
                                   5.575E-07
  1
EXCITED DIAMETER =  5.000E-01
  I     RAMP(I)       SEGSIR(I)      A(I+1)
```

TABLE 7.14 (CTD.)

1	5.808E-01	5.808E-01	1.097E-02
2	5.808E-01	5.808E-01	2.194E-02
3	5.808E-01	5.808E-01	3.290E-02
4	5.808E-01	5.808E-01	4.385E-02

TABLE 7.14 (CTD.)

FIGURE 7.10 EXAMPLE 2(B) – PLOTTED OUTPUT

TITLE PAGE

FOUR SEGMENT EXAMPLE
FREE END BOUNDARY CONDITION

FIGURE 7.10 (CTD.)

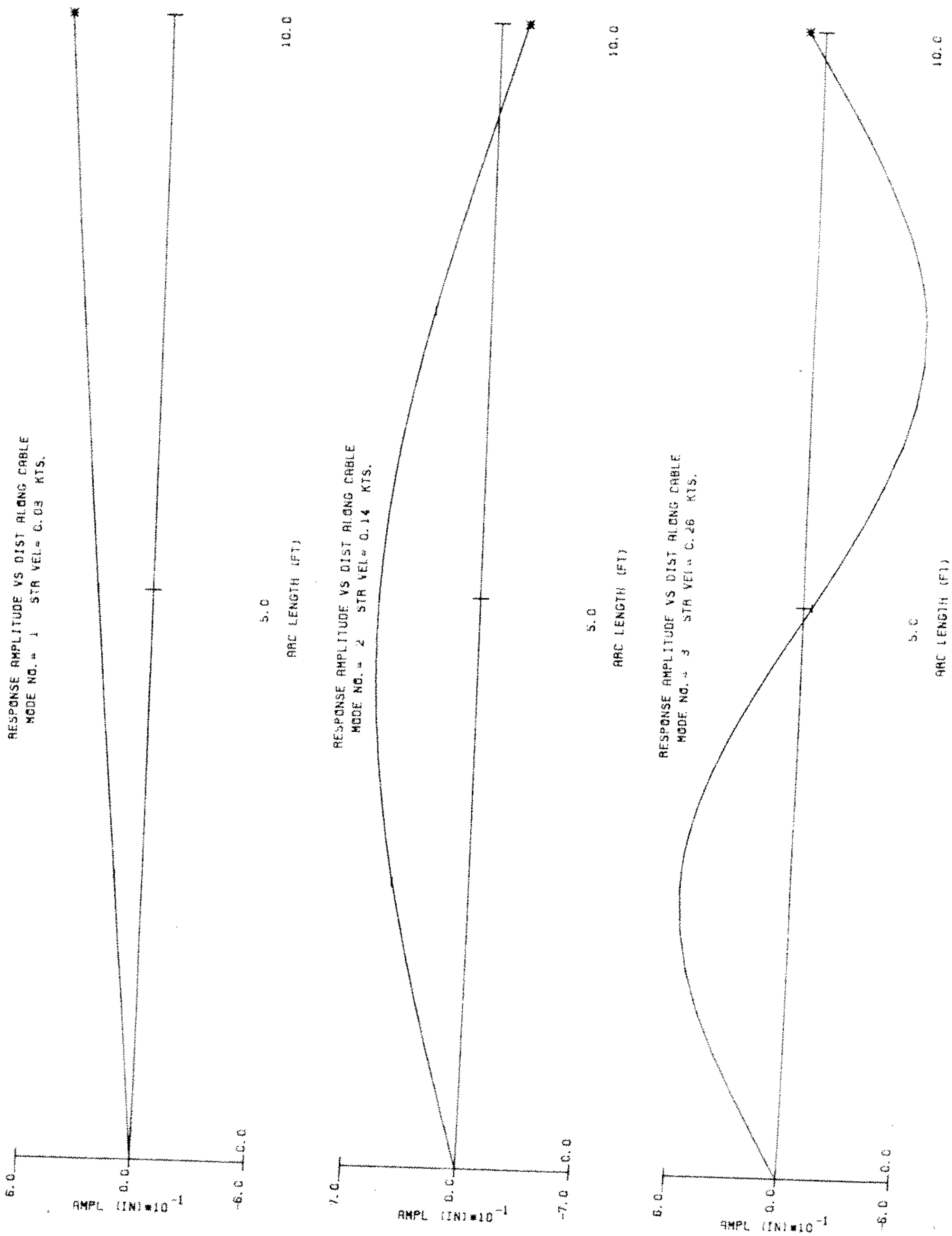


FIGURE 7.10 (CTD.)

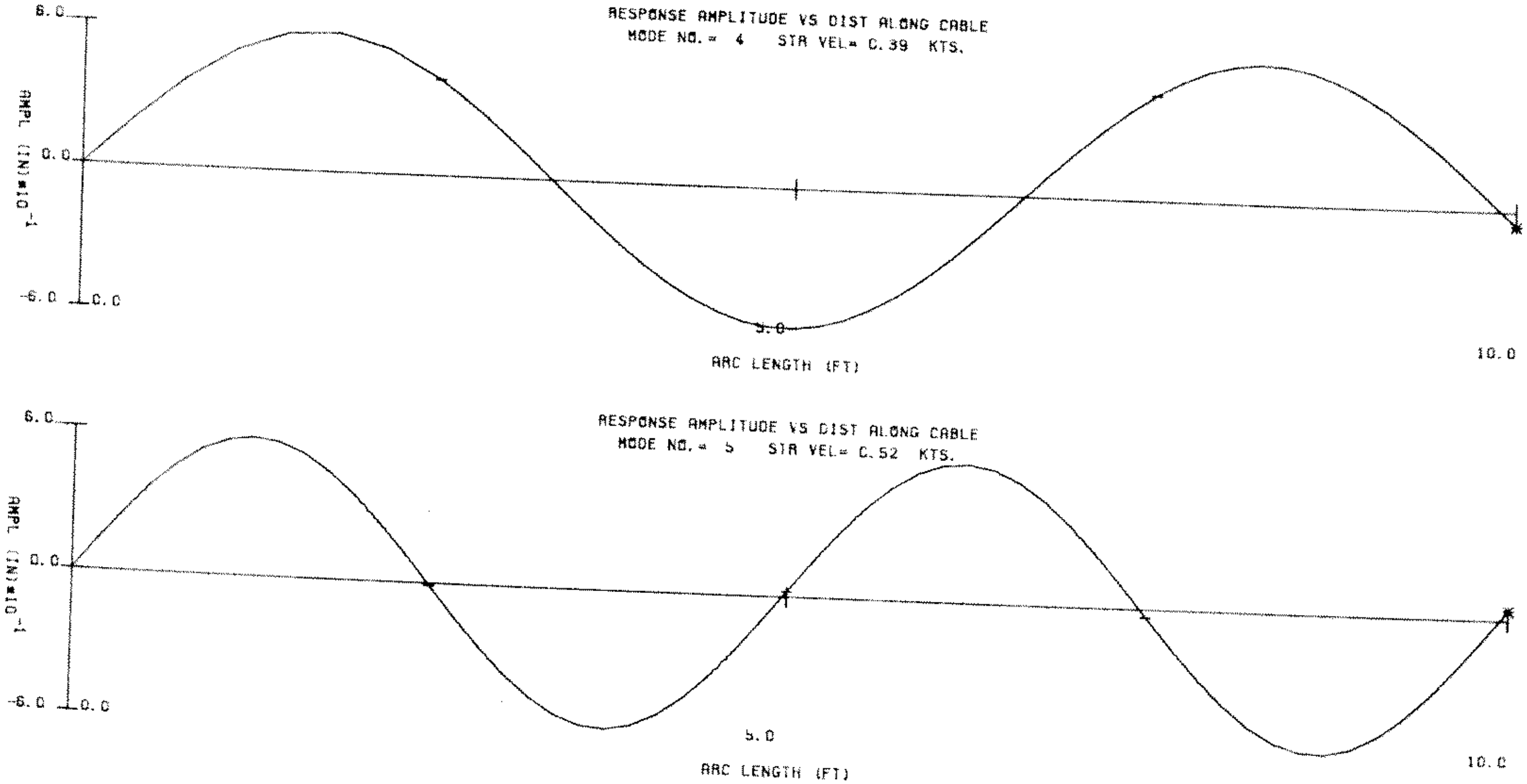
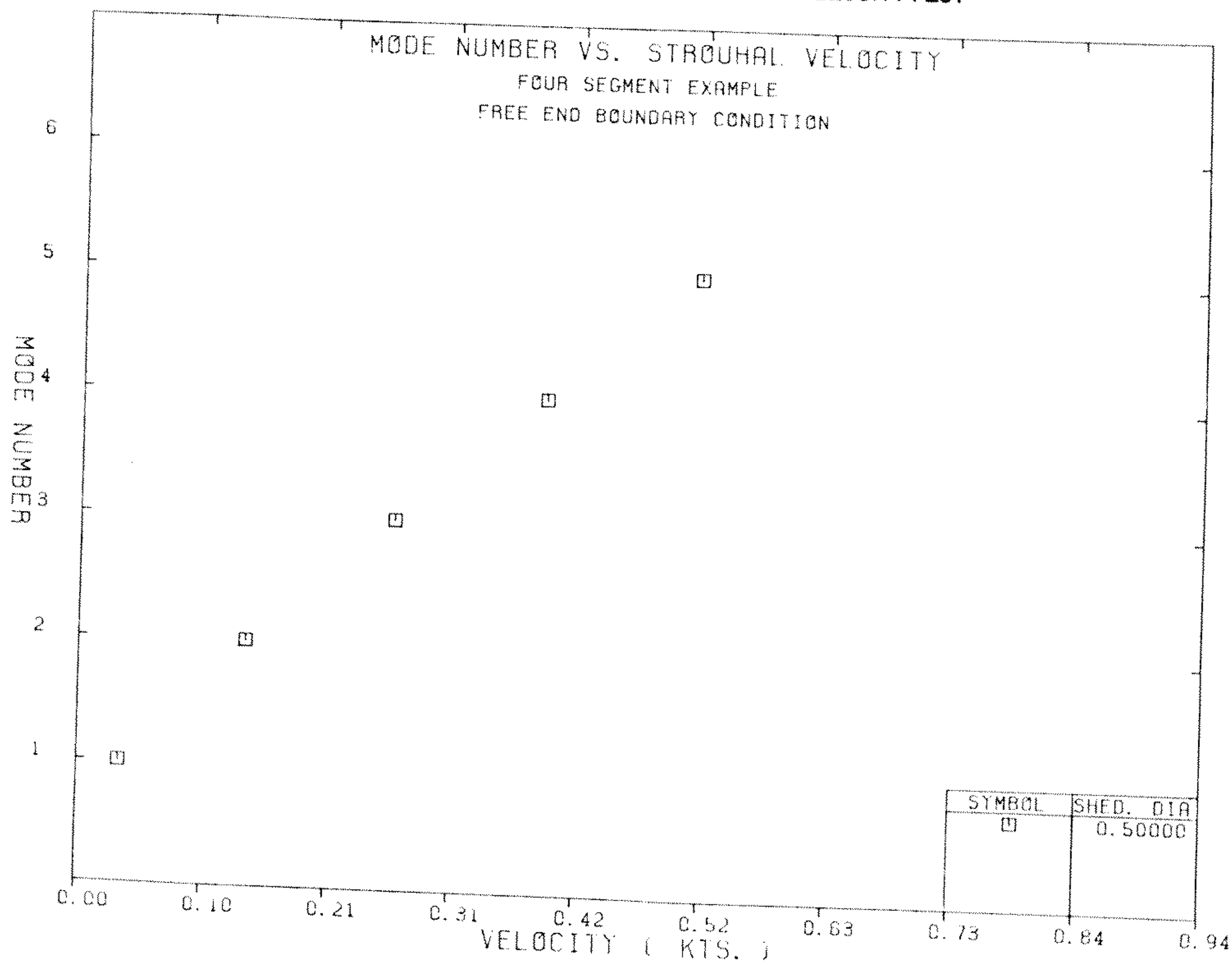


FIGURE 7.11 EXAMPLE 2(B) – MODE VS. VELOCITY PLOT



7.3 Example 3

The third example shows the response of a cable system when a spring-mass combination is added to the system (see Figure 7.12). Also illustrated is the form of the output when there are several distinct diameters in the cable system. The input data file is shown in Table 7.15, and the output listed in Table 7.16. The ADF is also given (Table 7.17). The plot type used is "Pagplt" (Figure 7.13). No mode vs velocity plot is produced, as the mode counting method used is not valid for this type of system (see 5.3.3). Note that the mode numbering is indeed incorrect in both the main output file and the ADF. The second two modes found are BOTH labeled "Mode 2".

Note that in the input data file, a spring-mass was erroneously generated at the end of segment 2. The program recognizes that this specification has no meaning when the boundary condition is fixed at this end, and zeroes out the spring and mass accordingly. This is verified by checking the output file (Table 7.16).

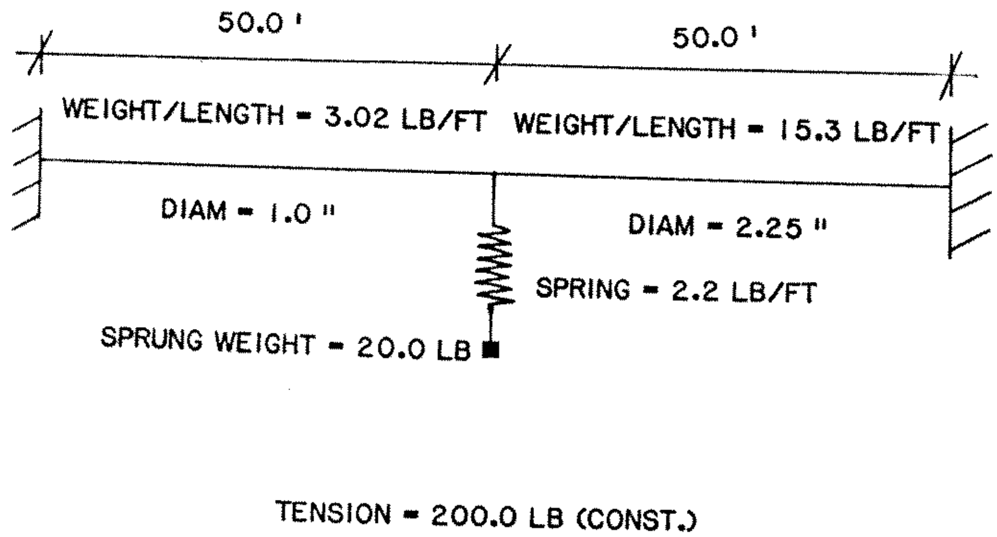


FIGURE 7.12 EXAMPLE 3

```
TEST EXAMPLE-NONUNIFORM CABLE DIAMETERS
   2          0.05     62.4
     50.0   2
      1.0     3.02    200.0      1.0
     2.25    15.30    200.0      1.0
              2.2      20.0
        3     0.0      10.0                        2
   1    2                             1.0E-5   2
   1
```

TABLE 7.15 EXAMPLE 3 - INPUT DATA FILE

TEST EXAMPLE-NONUNIFORM CABLE DIAMETERS

DATE - THU, MAR 29 1984 TIME - 09:47:52

+++++++++PROGRAM RUNNING IN SINGLE PRECISION+++++++++

N O T E S   O N   O U T P U T   D A T A

1. ALL WEIGHTS ARE TOTAL EFFECTIVE WEIGHTS AND INCLUDE EFFECTS OF ADDED WATER MASS.

2. MODE SEARCH VELOCITY LIMITS CALCULATED FROM STROUHAL'S RELATIONSHIP USE MIN. DIAMETER FOR LOWER LIMIT AND MAX. DIAMETER FOR UPPER LIMIT AND INCREMENT.

3. DRAG IS NOT CALCULATED ON SPRUNG MASSES.

4. TABULATED RESPONSE AMPLITUDES ARE ONE HALF OF THE PEAK TO PEAK RESPONSE.

5. IN THE OUTPUT DATA, AN ASTERISK (*) BESIDE A SEGMENT NO. INDICATES THAT THIS SEGMENT IS ACTIVE FOR THE PARTICULAR MODE AND FLOW VELOCITY, I.E. IT IS BEING EXCITED BY VORTEX SHEDDING.

INPUT DATA SET NO. 1

SEGMENT DEFINITION			CABLE SEGMENT DATA				ATTACHED WEIGHT DATA				SPRUNG WT DATA	
SEG NO	LENGTH (FT)	ARC LENGTH (FT)	DIAM (IN)	DRAG COEF	WT/LENGTH (LB/FT)	TENSION (LB)	ATTACHED WT (LB)	DRAG COEF	PROJ AREA (FT**2)	EFFECT DIA (IN)	ATT SPR (LB/FT)	SPRUNG WT (LB)
1	50.000	50.000	1.000E 00	1.00	3.020E 00	200.00	0.000E-01	0.00	0.000E-01	1.000E 00	2.20	20.00
2	50.000	100.000	2.250E 00	1.00	1.530E 01	200.00	0.000E-01	0.00	0.000E-01	1.000E 00	0.00	0.00

TOTAL NO OF SEGMENTS = 2

AVERAGE CABLE DRAG COEF = 1.000 BASED ON PROJECTED CABLE AREA OF 1.354E 01 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 0 MASSES AND PROJECTED AREA OF 0.000E-01 (FT**2)

MAXIMUM NO OF MODES SOUGHT = 3

BOUNDARY CONDITION AT END OF LAST SEGMENT : FIXED

TABLE 7.16 EXAMPLE 3 – OUTPUT DATA FILE

MODE SEARCH LIMITS

	LOWER LIMIT	UPPER LIMIT	INCREMENT
KNOTS	0.0000	5.2866	0.0009
HERTZ	0.0000	10.0000	0.0016
FT/SEC	0.0000	8.9286	0.0015
CM/SEC	0.0000	272.1428	0.0444
RAD/SEC	0.0000	62.8318	0.0103

FRACTION OF STRUCTURAL CRITICAL DAMPING IN AIR = 0.0500

FLUID DENSITY = 6.240E 01 (LB/FT*3)

FRACTION OF STRUCTURAL CRITICAL DAMPING IN FLUID = 0.0471

TABLE 7.16 (CTD.)

```
MODE NO    1

FREQUENCY =  7.778E-01 RAD/SEC     AVERAGE STROUHAL VELOCITY  4.912E-02 FT/SEC
          =  1.238E-01 HERTZ            BASED ON DIAMETER      1.497E 00 CM/SEC
                                        OF  1.000E 00 IN.      2.909E-02 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING =  4.720E-02   EFFECTIVE MASS PARAMETER =  8.765E 01

MAX DISPLACEMENT =  9.043E-03  OCCURING IN SEGMENT NUMBER   2

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) =    -0.000 %

        CABLE RESPONSE                MASS RESPONSE

SEGMENT   MAX SEG    DRAG COEF   MASS RESP  DRAG COEF  SPRING MASS              SEGMENT
  NO     AMPL (IN)               AMPL (IN)  ATT WTS.  NAT FREQ (HZ)        STROUHAL VELOCITY
  1 *    8.570E-03    1.052      8.570E-03   0.000        0.300        FT/SEC     CM/SEC     KNOTS
  2      9.043E-03    1.039      2.498E-10  BOUNDARY    BOUNDARY      4.912E-02 1.497E 00 2.909E-02
                                                                      1.105E-01 3.369E 00 6.544E-02

AVERAGE CABLE DRAG COEF =     1.043 BASED ON PROJECTED CABLE AREA OF  1.354E 01 (FT**2)

AVERAGE MASS DRAG COEF  =     0.000 OVER   0 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) =    4.275%

** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----

MODE NO    1

FREQUENCY =  7.778E-01 RAD/SEC     AVERAGE STROUHAL VELOCITY  1.105E-01 FT/SEC
          =  1.238E-01 HERTZ            BASED ON DIAMETER      3.369E 00 CM/SEC
                                        OF  2.250E 00 IN.      6.544E-02 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING =  4.870E-02   EFFECTIVE MASS PARAMETER =  9.880E 00

MAX DISPLACEMENT =  7.100E-01  OCCURING IN SEGMENT NUMBER   2

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) =    -0.000 %
```

TABLE 7.16 (CTD.)

SEGMENT NO	CABLE RESPONSE: MAX SEG AMPL (IN)	CABLE RESPONSE: DRAG COEF	MASS RESPONSE: MASS RESP AMPL (IN)	MASS RESPONSE: DRAG COEF ATT WTS.	SPRING MASS NAT FREQ (HZ)	SEGMENT STROUHAL VELOCITY FT/SEC	CM/SEC	KNOTS
1	6.729E-01	1.891	6.729E-01	0.000	0.300	4.912E-02	1.497E 00	2.909E-02
2 *	7.100E-01	1.657	1.961E-08	BOUNDARY	BOUNDARY	1.105E-01	3.369E 00	6.544E-02

AVERAGE CABLE DRAG COEF = 1.729 BASED ON PROJECTED CABLE AREA OF 1.354E 01 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 0 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) = 72.897%

** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----

MODE NO 2

FREQUENCY = 1.690E 00 RAD/SEC
= 2.690E-01 HERTZ

AVERAGE STROUHAL VELOCITY BASED ON DIAMETER OF 1.000E 00 IN. 1.067E-01 FT/SEC
3.254E 00 CM/SEC
6.320E-02 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING = 4.730E-02 EFFECTIVE MASS PARAMETER = 5.663E 01

MAX DISPLACEMENT = 2.094E-02 OCCURING IN SEGMENT NUMBER 2

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) = 0.000 %

SEGMENT NO	CABLE RESPONSE: MAX SEG AMPL (IN)	CABLE RESPONSE: DRAG COEF	MASS RESPONSE: MASS RESP AMPL (IN)	MASS RESPONSE: DRAG COEF ATT WTS.	SPRING MASS NAT FREQ (HZ)	SEGMENT STROUHAL VELOCITY FT/SEC	CM/SEC	KNOTS
1 *	1.796E-02	1.101	1.736E-02	0.000	0.300	1.067E-01	3.254E 00	6.320E-02
2	2.094E-02	1.059	3.704E-08	BOUNDARY	BOUNDARY	2.402E-01	7.321E 00	1.422E-01

AVERAGE CABLE DRAG COEF = 1.072 BASED ON PROJECTED CABLE AREA OF 1.354E 01 (FT**2)

AVERAGE MASS DRAG COEF = 0.000 OVER 0 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) = 7.221%

** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----

TABLE 7.16 (CTD.)

```
MODE NO    2

FREQUENCY =  1.690E 00 RAD/SEC    AVERAGE STROUHAL VELOCITY  2.402E-01 FT/SEC
          =  2.690E-01 HERTZ          BASED ON DIAMETER      7.321E 00 CM/SEC
                                      OF  2.250E 00 IN.      1.422E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING =  4.956E-02   EFFECTIVE MASS PARAMETER =  1.053E 01

MAX DISPLACEMENT =  6.816E-01  OCCURING IN SEGMENT NUMBER   2

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) =     0.000 %

        CABLE RESPONSE                 MASS RESPONSE

SEGMENT   MAX SEG   DRAG COEF   MASS RESP  DRAG COEF   SPRING MASS              SEGMENT
  NO      AMPL (IN)             AMPL (IN)   ATT WTS.  NAT FREQ (HZ)        STROUHAL VELOCITY
  1      5.846E-01    1.971     5.651E-01    0.000        0.300         FT/SEC     CM/SEC     KNOTS
  2 *    6.816E-01    1.572     1.206E-06  BOUNDARY     BOUNDARY       1.067E-01 3.254E 00 6.320E-02
                                                                     2.402E-01 7.321E 00 1.422E-01
AVERAGE CABLE DRAG COEF =     1.695 BASED ON PROJECTED CABLE AREA OF  1.354E 01 (FT**2)

AVERAGE MASS DRAG COEF  =     0.000 OVER   0 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) =   69.465%

** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----
MODE NO    2

FREQUENCY =  2.060E 00 RAD/SEC    AVERAGE STROUHAL VELOCITY  1.301E-01 FT/SEC
          =  3.279E-01 HERTZ          BASED ON DIAMETER      3.966E 00 CM/SEC
                                      OF  1.000E 00 IN.      7.703E-02 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING =  4.746E-02   EFFECTIVE MASS PARAMETER =  3.573E 01

MAX DISPLACEMENT =  4.993E-02  OCCURING IN SEGMENT NUMBER   1

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) =     0.000 %
```

TABLE 7.16 (CTD.)

```
        CABLE RESPONSE                    MASS RESPONSE

SEGMENT   MAX SEG    DRAG COEF   MASS RESP   DRAG COEF   SPRING MASS                  SEGMENT
  NO      AMPL (IN)              AMPL (IN)   ATT WTS.   NAT FREQ (HZ)           STROUHAL VELOCITY
  1 *     4.993E-02    1.204     3.946E-02    0.000        0.300          FT/SEC     CM/SEC     KNOTS
  2       4.140E-02    1.100     2.004E-08   BOUNDARY     BOUNDARY       1.301E-01 3.966E 00 7.703E-02
                                                                         2.927E-01 8.922E 00 1.733E-01
AVERAGE CABLE DRAG COEF =     1.132 BASED ON PROJECTED CABLE AREA OF  1.354E 01 (FT**2)

AVERAGE MASS DRAG COEF  =     0.000 OVER   0 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) =   13.178%

** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----

MODE NO    2

FREQUENCY =  2.060E 00 RAD/SEC     AVERAGE STROUHAL VELOCITY  2.927E-01 FT/SEC
          =  3.279E-01 HERTZ          BASED ON DIAMETER       8.922E 00 CM/SEC
                                      OF  2.250E 00 IN.       1.733E-01 KNOTS

EFFECTIVE FLUID/STRUCTURE DAMPING =  5.110E-02   EFFECTIVE MASS PARAMETER =  1.181E 01

MAX DISPLACEMENT =  5.963E-01  OCCURING IN SEGMENT NUMBER   1

ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PERCENT OF MAX. DISPLT....SEE USER MANUAL) =     0.000 %

        CABLE RESPONSE                    MASS RESPONSE

SEGMENT   MAX SEG    DRAG COEF   MASS RESP   DRAG COEF   SPRING MASS                  SEGMENT
  NO      AMPL (IN)              AMPL (IN)   ATT WTS.   NAT FREQ (HZ)           STROUHAL VELOCITY
  1       5.963E-01    2.024     4.712E-01    0.000        0.300          FT/SEC     CM/SEC     KNOTS
  2 *     4.944E-01    1.499     2.394E-07   BOUNDARY     BOUNDARY       1.301E-01 3.966E 00 7.703E-02
                                                                         2.927E-01 8.922E 00 1.733E-01
AVERAGE CABLE DRAG COEF =     1.661 BASED ON PROJECTED CABLE AREA OF  1.354E 01 (FT**2)

AVERAGE MASS DRAG COEF  =     0.000 OVER   0 MASSES AND PROJECTED AREA OF 0.000E-01

PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATTACHED MASSES (SEE USER MANUAL) =   66.058%

** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** --------- **** -----
```

TABLE 7.16 (CTD.)

```
TEST EXAMPLE-NONUNIFORM CABLE DIAMETERS
    1
 NSEG      NPLOT     PLEN      NCOUNT
   2         3        0.         6
   I        CL(I)          S(I)          D(I)          ALP(I)        AW(I)
   1      5.000E 01     5.000E 01     1.000E 00     2.166E-02     0.000E-01
   2      5.000E 01     1.000E 02     2.250E 00     4.874E-02     0.000E-01

 MODE NO =     1     FREQUENCY =     7.778E-01NO. ITERATIONS =    2
  IPSTRT            IPSTOP
   0                  0
   I       PHAS(I)       AMPL(I)        A(I)          B(I)        NZX(I)
   1     -1.571E 00     1.000E 00    -1.000E 00     0.000E-01       0
   2     -2.817E 00     7.873E-01    -2.512E-01    -7.461E-01       1
                                     -2.174E-08
   1
 EXCITED DIAMETER =   1.000E 00
   I       RAMP(I)       SEGSIR(I)      A(I+1)
   1      1.149E-02     8.570E-03     8.570E-03
   2      9.043E-03     9.043E-03     2.498E-10
   2
 EXCITED DIAMETER =   2.250E 00
   I       RAMP(I)       SEGSIR(I)      A(I+1)
   1      9.019E-01     6.729E-01     6.729E-01
   2      7.100E-01     7.100E-01     1.961E-08

 MODE NO =     2     FREQUENCY =     1.690E 00NO. ITERATIONS =    2
  IPSTRT            IPSTOP
   1                  2
   I       PHAS(I)       AMPL(I)        A(I)          B(I)        NZX(I)
   1     -1.571E 00     1.000E 00    -1.000E 00     0.000E-01       0
   2      2.548E 00     1.166E 00     6.518E-01    -9.666E-01       2
                                      2.062E-06
   1
 EXCITED DIAMETER =   1.000E 00
   I       RAMP(I)       SEGSIR(I)      A(I+1)
   1      1.796E-02     1.796E-02     1.736E-02
   2      2.094E-02     2.094E-02     3.704E-08
   2
 EXCITED DIAMETER =   2.250E 00
   I       RAMP(I)       SEGSIR(I)      A(I+1)
   1      5.846E-01     5.846E-01     5.651E-01
   2      6.816E-01     6.816E-01     1.206E-06

 MODE NO =     2     FREQUENCY =     2.060E 00NO. ITERATIONS =    3
```

TABLE 7.17 EXAMPLE 3 – AUXILIARY DATA FILE

```
IPSTRT         IPSTOP
  1              2
 I       PHAS(I)        AMPL(I)        A(I)           B(I)         NZX(I)
  1     1.571E 00      1.000E 00      1.000E 00      0.000E-01        0
  2     3.080E-01      8.292E-01      2.514E-01      7.902E-01        2
                                      4.014E-07
  1
EXCITED DIAMETER =  1.000E 00
 I       RAMP(I)        SEGSIR(I)      A(I+1)
  1     4.993E-02      4.993E-02      3.946E-02
  2     4.140E-02      4.140E-02      2.004E-08
  2
EXCITED DIAMETER =  2.250E 00
 I       RAMP(I)        SEGSIR(I)      A(I+1)
  1     5.963E-01      5.963E-01      4.712E-01
  2     4.944E-01      4.944E-01      2.394E-07
```

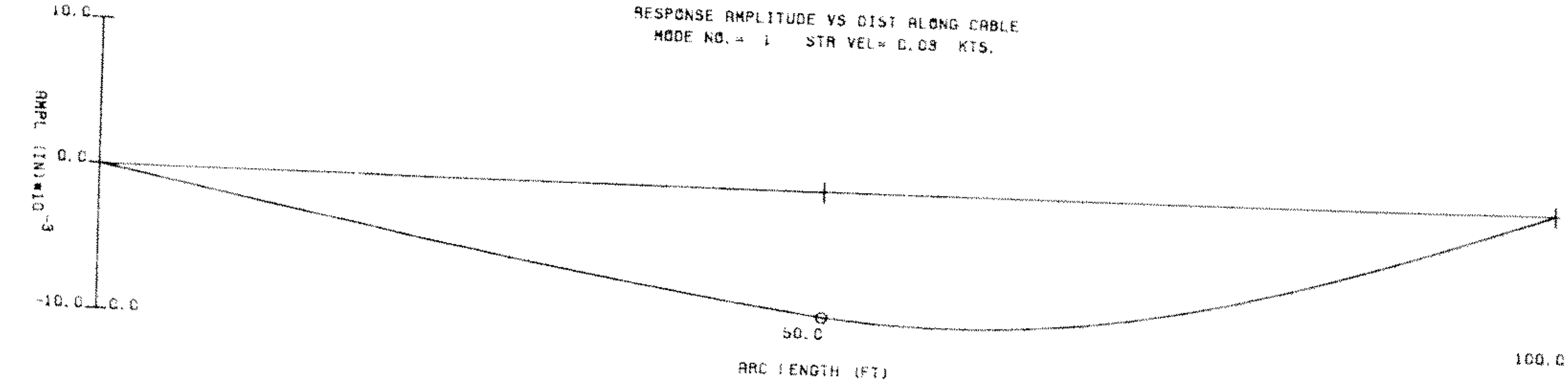
TABLE 7.17 (CTD.)

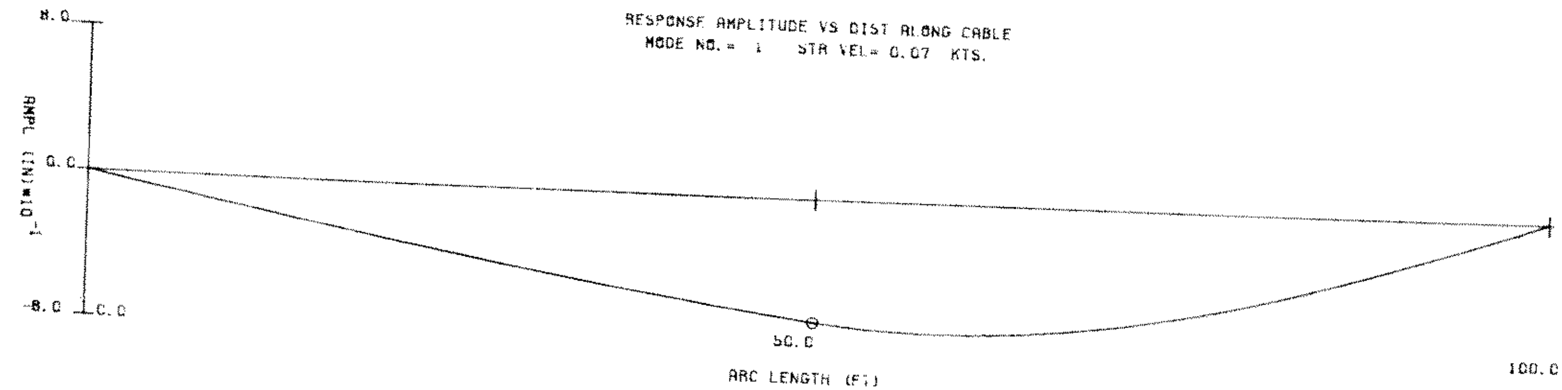
FIGURE 7.13 EXAMPLE 3 – PLOTTED OUTPUT

TITLE PAGE

TEST EXAMPLE-NONUNIFORM CABLE DIAMETERS

FIGURE 7.13 (CTD.)





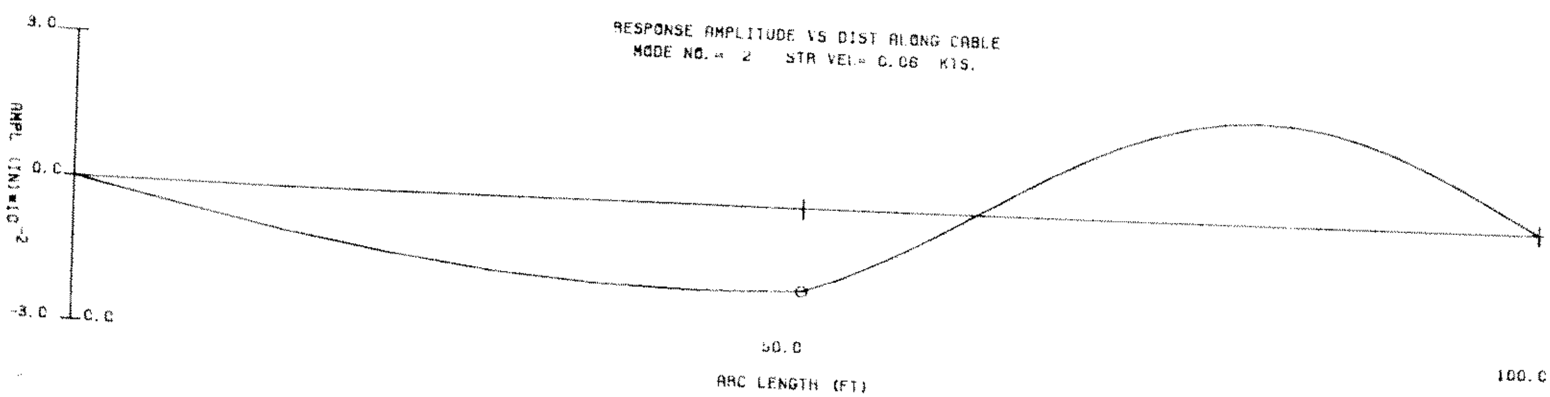
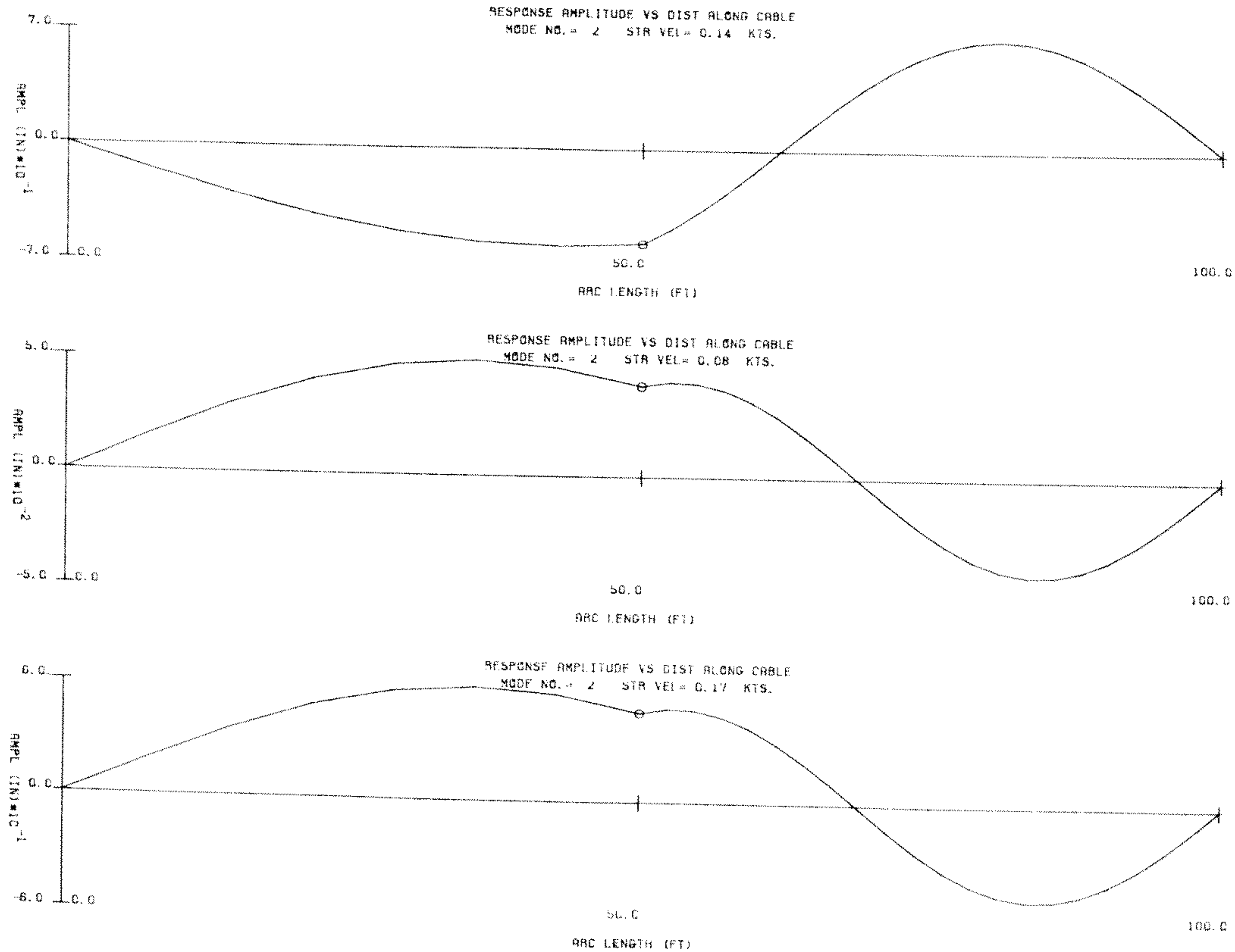


FIGURE 7.13 (CTD.)



REFERENCES

1. Iwan, W. D., "The Vortex Induced Oscillation of Elastic Structural Elements," Journal of Engineering for Industry, Nov. 1975, pp. 1378-1382.

2. Iwan, W. D., "Dynamic Response of Suspended Underwater Systems," Journal Acoustical Society of America, Vol. 51, No. 5, 1972, pp. 1688-1696.

3. Iwan, W. D., and Blevins, R. D., "A Model for Vortex Induced Oscillation of Structures," Journal of Applied Mechanics, Vol. 41, No. 3, Sept. 1974, pp. 581-586.

4. Sergev, S., and Iwan, W. D., "The Natural Frequencies and Mode Shapes of Cables with Attached Masses," NCEL TM No. M-44-79-3, April 1979.

5. Skop, R. A., Griffin, O. M., and Ramberg, S. E., "Seacon II Strumming Predictions," NRL Memorandum Report 3383, October 1976.

APPENDIX I - NEWTON-RAPHSON ALGORITHM FOR DAMPING FACTOR.

The effective fraction of critical damping ζ_k^s must be solved for in a numerical manner. ζ_k^s and $P^{(k)}$ both appear in Equations 2-34 and 2-36 which must be solved simultaneously using a Newton-Raphson technique.

Let Equation 2-36 define a function $f(\zeta_k^s)$, which must necessarily vanish. That is,

$$f(\zeta_k^s) \equiv \zeta_k^s - \zeta_k^0 - P^{(k)}\Phi^{(k)} = 0 \qquad \text{(I-1)}$$

Substitution of Eq. 2-34 yields

$$f(\zeta_k^s) \equiv \zeta_k^s - \zeta_k^0 - \frac{\Phi^{(k)}}{1 + 9.60(\mu_r^{(k)}\zeta_k^s)^{1.8}} = 0 \qquad \text{(I-2)}$$

Equation I-2 may now be solved by the Newton-Raphson technique. Let $\zeta_{k_i}^s$ be the ith iterate of ζ_k^s. Then,

$$\zeta_{k_{i+1}}^s = \zeta_{k_i}^s - \frac{f(\zeta_{k_i}^s)}{\dfrac{df}{d\zeta_k^s}(\zeta_{k_i}^s)} \qquad \text{(I-3)}$$

where

$$\frac{df}{d\zeta_k^s}(\zeta_{k_i}^s) = 1 + \frac{17.28\mu_r^{(k)^{1.8}}(\zeta_{k_i}^s)^{0.8}}{(1 + 9.6(\mu_r^{(k)}\zeta_{k_i}^s)^{1.8})^2}\Phi^{(k)} \qquad \text{(I-4)}$$

Iteration continues until the change in ζ_k^s is less than some prescribed tolerance.

APPENDIX II - SIMPLIFICATION OF INTEGRALS IN CHAPTER 2

Many of the integrals involved in the solution parameters $\Phi^{(k)}$, $\hat{I}^{(k)}$, etc., may be evaluated analytically in terms of the mode shape parameters $A_i^{(k)}$ and $B_i^{(k)}$. It may, for example, be shown that

$$\int_0^{\ell_i} [Y_i^{(k)}(x)]^2 dx = \frac{[(A_i^{(k)})^2 + (B_i^{(k)})^2]}{\alpha_i \omega_k} \times \left[\frac{1}{2}(\alpha_i \omega_k \ell_i) + \frac{1}{4}\left[\sin 2(\alpha_i \omega_k \ell_i - \phi_i^{(k)}) + \sin 2\phi_i^{(k)}\right]\right] \quad \text{(II-1)}$$

$$\int_0^{\ell_i} [Y_i^{(k)}(x)]^4 dx = \frac{[(A_i^{(k)})^2 + (B_i^{(k)})^2]^2}{\alpha_i \omega_k} \times \left[\frac{3}{8}(\alpha_i \omega_k \ell_i) + \frac{3}{16}\left[\sin 2(\alpha_i \omega_k \ell_i - \phi_i^{(k)}) + \sin 2\phi_i^{(k)}\right] + \frac{1}{4}\left[\cos^3(\alpha_i \omega_k \ell_i - \phi_i^{(k)})\sin(\alpha_i \omega_k \ell_i - \phi_i^{(k)}) + \cos^3\phi_i^{(k)} \sin\phi_i^{(k)}\right]\right]$$

.... (II-2)

where

$$\phi_i^{(k)} = \tan^{-1}\left[\frac{A_i^{(k)}}{B_i^{(k)}}\right] \quad \text{(II-3)}$$

The evaluation of the integral involving the cubic term $|Y_i^{(k)}(x)|^3$ appearing in Eq 2.36 uses an algorithm which may be observed in subroutine *IMODE*, and will not be discussed here.

APPENDIX III - MODIFICATION OF DAMPING RATIO BY FLUID

One of the input parameters for NATFREQ is ZETA, the fraction of structural critical damping in air. The medium is specified as air as it is considered that tests to determine this value would be performed in air, rather than in the fluid where the cable system would ultimately be located.

However, a correction can be made to this value to allow for the prescence of the fluid. As the input parameter is an "average" value over the whole cable, the assumptions used in this approximate analysis produce a modified value of a comparable order of approximation.

Consider the equation of motion for a forced single degree of freedom oscillator vibrating in a fluid of density ρ_f. Fluid damping effects are not considered for this discussion. The equation is written

$$M\ddot{x} + c\dot{x} + kx = F(t) \qquad \text{(III-1)}$$

where x is the displacement of the mass, including added fluid mass, M. The viscous structural damping coefficient is c, and k is the spring stiffness. F(t) is some applied force as a function of time. This equation may also be written

$$\ddot{x} + 2\zeta_f\omega_n\dot{x} + \omega_n^2 x = \frac{F(t)}{M} \qquad \text{(III-2)}$$

where

$$\omega_n^2 = k/M \qquad \text{(III-3)}$$

and

$$\zeta_f = \frac{c}{2(kM)^{1/2}} \qquad \text{(III-4)}$$

ζ_f is called the fraction of critical structural damping in the fluid. The corresponding value in air is defined as

$$\zeta_{air} = \frac{c}{2(km)^{1/2}} \qquad \text{(III-5)}$$

where m is the mass of the body excluding added fluid mass, m_f. That is

$$m = M - m_f \qquad \text{(III-6)}$$

The added fluid mass is given by

$$m_f = K\,m' \qquad \text{(III-7)}$$

where m' is mass of the fluid displaced by the body, and K is the added mass coefficient. For a cylinder, K may be shown analytically to be 1.

To convert from ζ_{air} to ζ_f, the following expression is used.

$$\zeta_f = \zeta_{air}\left[\frac{m}{M}\right]^{1/2} \qquad \text{(III-8)}$$

or

$$\zeta_f = \zeta_{air}\left[\frac{m}{m + m_f}\right]^{1/2} \qquad \text{(III-9)}$$

Now, for the cable system, the values m and m_f may be replaced by the corresponding mass values for the entire cable system, or by using the average density of the cable.

$$\zeta_f = \zeta_{air} \left[\frac{\rho_{ave}}{\rho_{ave} + \rho_f}\right]^{1/2} \qquad \text{(III-10)}$$

where ρ_{ave} is the average density of the cable.

Equation III-10 is the expression used to modify the input value of ZETA to allow for the prescence of the fluid. The correction is applied in subroutine READ.

APPENDIX IV - COMMON BLOCK STRUCTURE.

A description below is given of the common blocks used in NATFREQ. It is considered that this may be useful in making additions or alterations to the program. In most cases, the contents of a block are grouped according to the nature of the data it contains. For example, all the information related to plotting is contained in the common block called "PLTINF".

Common Block C1

General segment data as input or calculated.

CL(I) : cable segment lengths, in feet.

D(I) : cable diameters, in inches.

WC(I) : weight per unit length of cable segment, in pounds per foot.

TC(I) : tension in cable segment, in pounds.

AW(I) : attached weight at end of segment, in pounds.

NZX(I) : number of zero crossings calculated in segment.

ALP(I) : parameter α_i for cable segment, in seconds per foot.

S(I) : total arc length to end of segment,in feet.

NSEG : number of cable segments for problem.

Common Block C2

Calculated modal coefficients, amplitudes, and phases.

A(I), B(I) : coefficients A_i and B_i , in Equation 3.

AMPL(I) : amplitude of mode shape in segment.

PHAS(I) : phase of mode shape in segment, in radians.

RAMP(I) : strumming amplitude of cable in segment, in inches.

Common Block C3

Drag coefficients, projected areas, etc. (input and modified).

CDC(I) : coefficient of drag input for cable segment

CDA(I) : coefficient of drag input for attached weight.

DEFF(I) : effective diameter of attached weight at end of segment, in inches.

PRA(I) : effective projected frontal area of attached mass, in square feet.

CD(I) : coefficient of drag for strumming cable segment.

CDAR(I) : coefficient of drag on attached weight for strumming cable.

Common Block C4

Mode shape coefficients in double precision.

AD(I), BD(I) : coefficients A_i and B_i , in double precision.

Common Block C5

Sprung mass data.

STIF(I) : stiffness of attached spring at end of segment, in pounds per foot.

STWT(I) : sprung mass at end of segment, in pounds.

OMNAT(I) : spring-mass natural frequency, in rad/sec.

Common Block C6

This block contains the integrals of the mode shape, raised to various powers, as needed for $\hat{I}^{(k)}$ and $\Phi^{(k)}$, as required in Equations 26 and 33, respectively.

F2 : integral of mode shape squared.

F3 : integral of mode shape modulus cubed.

F4 : integral of mode shape to fourth power.

FG : integral appearing in Equation 2-32.

PIM : quotient of F4 and F2.

Common Block C7

Fluid properties, damping, shedding diameter, and general model parameters.

CP(I) : parameter indicating whether a segment is active (= 1) or not (= 0).

DS : diameter of strumming segment, in inches.

ZETA : fraction of critical damping for cable in air, later modified for fluid

ZETAE : effective fluid/structure fraction of critical damping.

RHOW : weight density of fluid, in pounds per cubic foot.

RMU : effective mass parameter, $\mu_r^{(k)}$, defined in Equation 31.

Common Block C8

Averages and related parameters for drag coefficients.

CPRA : projected area of whole cable, in square feet.

PRASUM : total projected area of attached weights, in square feet.

CDT : average drag coefficient for strumming cable, based on cable only.

CDTOT : average drag coefficient for strumming cable, cable and weights.

CDWT : average drag coefficient for strumming cable, added weights only.

CDCAV : average drag coefficient for cable, based on input drag coefficients.

CDAAV : average drag coefficient for attached weights, based on input data.

Common Block CONST

Mathematical and model constants.

PI : constant π.

STRHN : Strouhal Number, set as 0.21 in program.

Common Block DEVICE

The parameters described below are set in the "BLOCK DATA" subprogram. Initially supplied values are set as IIN=5, IOUT=6, and IADF=8. When the program is installed, these may need to be altered for a specific site before compilation.

IIN : device number for input device.

IOUT : device number for output device.

IADF : device number for auxiliary data file output.

Common Block DIAM

Distinct diameters stored for calculating active segments.

DU(I) : array of distinct diameters, in inches.

NOD : number of distinct diameters in array DU(I).

Common Block MODE

Details of mode search information.

MXMDS : maximum number of modes sought.

OMSTRT : lower limit of search interval, in units specified by UNITS.

OMSTOP : upper limit of search interval, in units as above.

DELOM : frequency search increment, in units as above.

ACC : desired accuracy of convergence (see Chapter 6).

ITCT : number of iterations required to converge to particular frequency.

IAPROX : code for output*which specifies if approximations were made due to lack of convergence.

IBCODE : "right hand end" boundary condition code. Either fixed end (= 0), or free end (= 1).

Common Block MXAMP

This block contains the details of maximum amplitudes within segments, and over the whole cable.

SEGSIR(I) : maximum strumming amplitude within a segment, in inches.

SEGSIZ(I) : maximum modal amplitude within a segment.

MXSEG : number of segment where maximum amplitude occurs.

BSIZE : maximum modal amplitude for whole cable.

BPSIZE : maximum modal amplitude over specified plotting range.

BSIZER : maximum strumming amplitude for whole cable, in inches.

BPSIZR : maximum strumming amplitude over specified plotting range, in inches.

Common Block OUTLOC

Variables controlling the output are stored in this block.

SPLOC(I) : array containing specified locations, in feet from "left hand end" of cable, where printed output is given.

IOUTCD : output type specification code (see Chapters 4 and 5).

NSPEC : number of specified locations where output is given.

Common Block PLTINF

Plotting control information.

IPLTCD : plot type specification code (see Chapters 4 and 5).

PLEN : length of abscissa of plot, in inches.

IPSPEC : code indicating plotting over a specified range (= 1) or not (= 0).

IPSTRT : if IPSPEC = 1, gives segment number for beginning of plot range.

IPSTOP : if IPSPEC = 1, gives segment number for end of plot range.

TITLE : title read on first input line, and plotted on graphs.

Common Block SRCPAR

Parameters used or generated while searching for natural frequencies.

OMCD : natural frequency, in radians/sec and double precision.

OMP : "previous estimate" of OMCD, before oscillating convergence occurs.

BP : "previous estimate" of the end boundary condition, associated with OMCD.

B2 : "upper estimate" of boundary condition when oscillating convergence occurs.

X2 : "upper estimate" of natural frequency, associated with B2.

ISERCH : flag indicating whether or not a previous boundary condition estimate exists.

Common Block VELPLT

Arrays containing data necessary to produce a plot of mode number versus Strouhal velocity, if required.

V(I) : array of Strouhal velocities associated with mode numbers given below, in units specified by UNITS parameter input.

MODNO(I) : array of mode numbers found within search limits.

APPENDIX V - SITE SPECIFIC INSTALLATION INSTRUCTIONS.

This appendix contains information for system operators, or users, involved in the installation or editing of NATFREQ on the host computer.

V.1 Double or Single Precision

As discussed in Chapter 6, it may be necessary to run the program in double precision to overcome convergence difficulties. The program contains blocks in (almost) all the subroutines with commented lines necessary to make the program double precision. To make the conversion, simply scan the program file for these blocks and replace the "C" in the first column of the executable statements with a space character. In subroutine READ, the REAL statement must also be changed to DOUBLE PRECISION to be compatible. Recompile and link in the normal way. The program should now run in double precision. Do not attempt to perform this procedure on only one subroutine, as linking will not be possible.

V.2 Dimensioning of Arrays

NATFREQ does not use dynamic allocation for dimensioning arrays. As supplied, all arrays are dimensioned for a maximum of 400 segments i.e. dimensioned to 401. If it is not envisaged that such large problems will be run, these dimension statements may be altered so as to use less total storage. Remember that the dimension must always be one more than the maximum number of segments. To make this adjustment, simply use the editor to scan for all the common blocks or dimension statements and change to the desired value.

V.3 Program Defaults

Some defaults for input parameters are included in NATFREQ. Two others, namely the coefficients of drag for the cable, and attached weights, were included in commented form only. It was not felt justified in making them 1.0, as some users may specifically require 0.0. If the default of 1.0 is desired, "uncomment" these lines in subroutine READ. Thereafter, to enter a zero value, simply input a small number like $1x10^{-5}$.

V.4 Width Specifiers

NATFREQ outputs 130 columns in the main output file. Make sure that the specific host system is set up to produce output of this width, or some of the output data will be lost.

V.5 Output Files

NATFREQ writes three types of output file. These are the main output file, the auxiliary data file, and the plot file. The default units for the first two files are assumed to be 6, and 8 respectively. These may changed in the routine BLOCK DATA. The plot file unit number will depend on the site, and should be checked with the operator. When running the program, make sure that all the necessary units have been opened. Regardless of whether or not a main output file is to be written, open the appropriate unit, as program error messages are written there.

V.6 Input Files

NATFREQ accepts two input files : the standard input file and the auxiliary data file. The default unit (which again may be changed in

BLOCK DATA) is 5. The program automatically determines which type of file is being sent. Ensure that unit 5 is opened for reading before running the program.

V.7 Mode Number Correction

At the end of subroutine ZEROX, there are several commented out statements. These are included as an option for large problems when mode number counting problems arise (see Chapter 6). Although it is not guaranteed that incorporation of these lines will solve the problem, it has been found to work in some cases. Simply uncomment the lines as described in V.1 and recompile the program to put the modification into effect.

APPENDIX VI- PROGRAM SOURCE LISTING.

The following pages contain the FORTRAN source code for the program NATFREQ.

```
*DECK NATFREQ
      PROGRAM NATFREQ(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE8)
C
C.....MAIN PROGRAM
C
C***************************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***************************************************************************
C
      DOUBLE PRECISION OMCD,OMP,BP,B2,X2,BX
      INTEGER UNITS,TITLE
C
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1          ALP(401),S(401),NSEG
      COMMON/C7/CP(401),DS,ZETA,ZETAE,RHOW,RMU
      COMMON/DEVICE/IIN,IOUT,IADF
      COMMON/DIAM/DU(401),NOD
      COMMON/MODE/MXMDS,OMSTRT,OMSTOP,DELOM,ACC,ITCT,IAPROX,IBCODE
      COMMON/OUTLOC/SPLOC(401),IOUTCD,NSPEC
      COMMON/PLTINF/IPLTCD,PLEN,IPSPEC,IPSTRT,IPSTOP,TITLE(8)
      COMMON/SRCPAR/OMCD,OMP,BP,B2,X2,ISERCH
C
C***************************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     ABS(X)      = DABS(X)
C
C***************************************************************************
C
C.....SET FUNCTIONS AND CONSTANTS
C
      JPLTNO = 0
      ND     = 1
C
C.....READ TITLE, PRINT TITLE, DATE, AND GENERAL INFORMATION
C
   10 CALL TITLRD(IEOF,ND,IDAT)
      IF(IEOF.EQ.1) GO TO 9999
      IF(IDAT.EQ.0) GO TO 15
C
C.....BRANCH FOR ANALYSIS DATA FILE PROCESSING
C
      CALL NATAUX
      GO TO 10
C
C.....READ INPUT DATA
C
   15 CALL READ(UNITS,DMAX,DMIN,IAUX,NMASS)
      IF(IOUTCD.EQ.0 .AND. IPLTCD.EQ.0 .AND.IAUX.EQ.0)GOTO 60
C
C.....FIND NO. OF DISTINCT DIA AND STORE
C
      CALL DISDIA
C
C.....WRITE AUXILLIARY DATA FILE (GENERAL INFO., SEGMENT DATA)
C
      NCOUNT = MXMDS*NOD
      IF(IAUX.EQ.1)CALL WRTAX1(NCOUNT)
C
      IAPROX = 0
      NROOT = 1
C
C.....BEGIN SEARCH FOR NATURAL FREQUENCIES
C
      OMP    = -1.0D0
      ISERCH = 0
      OMCD   = OMSTRT
```

```
   20 IF (OMCD.GE.(OMSTOP +DELOM/10.D0))GO TO 50
      CALL SEARCH(NSEG,OMC,BX)
C
C.....CALCULATE NO. ZEROXINGS AND IDENTIFY MODE NO.
C
      CALL ZEROX(OMCD,MNO,BX)
C
C.....WRITE AUXILLIARY DATA FILE (MODAL DATA)
C
      IF(IAUX.EQ.1)CALL WRTAX2(OMC,MNO)
C
C.....LOOP FOR ALL DISTINCT DIAMETERS
C
      DO 40 K = 1,NOD
      DS = DU(K)
C
C.....FORM COUPLING ARRAY
C
      DO 30 I = 1,NSEG
      CP(I) = 0.D0
      IF(ABS((D(I)-DS)/DS).LT.5.0D-4)CP(I) = 1.D0
   30 CONTINUE
C
C.....CALCULATE IM FACTOR AND OTHER INTEGRALS
C
      CALL IMODE(OMC)
C
C.....CALCULATE EFFECTIVE DAMPING FACTOR AND MASS
C
      CALL DAMP(NSEG)
C
C.....CALCULATE TRUE RESPONSE AMPLITUDE FOR EACH SEGMENT
C
      CALL RESAMP(NSEG)
C
C.....WRITE AUXILLIARY DATA FILE (AMPLITUDES)
C
      IF(IAUX.EQ.1)CALL WRTAX3(K,NSEG)
C
C.....CALCULATE CD/CDO FOR EACH CABLE SEGMENT
C
      CALL SEGDRG(OMC)
C
C.....CALCULATE TOTAL DRAG COEF
C
      CALL TCDRG
      CALL TWDRG(NSEG)
C
C.....WRITE OUT RESULTS FOR THIS MODE
C
      IF(IOUTCD.GT.0)CALL WRITE(OMC,MNO,STRVEL,BX,NMASS)
C
C.....STORE MODE NO AND FREQUENCY FOR PLOTTING
C
      IF(IPLTCD.GE.3)CALL STORE(OMC,MNO,NROOT,DS,UNITS,K)
C
C.....PLOT RESULTS IF SO DESIRED
C
      NROOTK = (NROOT-1)*NOD + K
      IF(IPLTCD.EQ.0 .OR. IPLTCD.EQ.5)GOTO 40
      IF(IPSTRT.EQ.0)IPSTRT=1
      IF(IPSTOP.EQ.0)IPSTOP=NSEG
      CALL CONVRT(OMC,DS,HOMC,VELFT,VELCM,STRVEL)
      CALL PLTCTL(OMC,MNO,DS,STRVEL,NROOTK,JPLTNO)
   40 CONTINUE
C
C.....RESTART SEARCH FOR NEW MODES
C
      BP    = B2
      OMP   = X2
```

```
      OMCD  = OMP  + DELOM
      NROOT = NROOT  + 1
      IF(NROOT.LE.MXMDS)GO TO 20
C
C.....PLOT MODE NUMBER VS STROUHAL VELOCITY
C
      IF(IPLTCD.GE.3)CALL MODPLT(NROOT,NROOTK,DMAX,DMIN,UNITS,JPLTNO)
C
C.....SEARCH COMPLETE READ NEW DATA SET
C
   50 ND = ND  + 1
      GO TO 10
C
   60 WRITE(IOUT,2001)
 2001 FORMAT(//," EXECUTION TERMINATED...NO OUTPUT OR PLOTS REQUESTED...
     1CHECK INPUT DATA FILE")
C
C.....CLOSE PLOT IF PLOT WAS PRODUCED
C
 9999 IF(JPLTNO.NE.0)CALL PLOT(1.,1.,999)
      STOP
      END
C
C-----------------------------------------------------------------------
C
      BLOCK DATA
C
C.....DEFINES CONSTANTS AND INPUT/OUTPUT DEVICES
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      COMMON/CONST/PI,STRHN
      COMMON/DEVICE/IIN,IOUT,IADF
C
      DATA IIN,IOUT,IADF/5,6,8/
      DATA PI/3.141592653589793D0/
      DATA STRHN/0.21D0/
C
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE AMPH(OMC,I)
C
C.....SUBROUTINE TO CALCULATE NOMINAL AMPLITUDE AND PHASE OF MODE SHAPE
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      DOUBLE PRECISION AD,BD,OMC
C
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1         ALP(401),S(401),NSEG
      COMMON/C2/A(401),B(401),AMPL(401),PHAS(401),RAMP(401)
      COMMON/C4/AD(401),BD(401)
      COMMON/CONST/PI,STRHN
      COMMON/MXAMP/SEGSIR(401),SEGSIZ(401),MXSEG,BSIZE,BPSIZE,BSIZER,
     1          BPSIZR
      COMMON/PLTINF/IPLTCD,PLEN,IPSPEC,IPSTRT,IPSTOP,TITLE(8)
C
      AMPL(I) =  DSQRT(AD(I)**2  + BD(I)**2)
```

```
      PHAS(I) =  DATAN2(AD(I),BD(I))
C
C.....FIND THE MAXIMUM AMPLITUDE OF RESPONSE
C
      PHIL = PHAS(I)/ALP(I)/OMC
      IF (PHAS(I) .LT. 0.D0) GOTO 10
      IF (CL(I) .GE. PHIL) GOTO 20
      GOTO 30
   10 IF (CL(I) .GE. (PI/ALP(I)/OMC + PHIL)) GOTO 20
      GOTO 30
   20 SEGSIZ(I) = AMPL(I)
      GOTO 40
   30 SEGSIZ(I) = DABS(BD(I+1))
      IF(DABS(BD(I)).GT.DABS(BD(I+1)))SEGSIZ(I) = DABS(BD(I))
   40 IF(SEGSIZ(I).LE.BSIZE)GOTO 50
      BSIZE = SEGSIZ(I)
      MXSEG = I
C
C.....FIND MAXIMUM AMPLITUDE OVER SPECIFIED PLOTTING RANGE
C
   50 IF(IPSPEC.EQ.0)GOTO 60
      IF(I.LT.IPSTRT .OR. I.GT.IPSTOP)GOTO 60
      IF(I.EQ.IPSTRT)BPSIZE=DABS(BD(I))
      IF(SEGSIZ(I).GT.BPSIZE)BPSIZE = SEGSIZ(I)
   60 CONTINUE
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE AMPLOT(OMC,BSCAL,DELTX)
C
C.....SUBROUTINE TO PLOT AMPLITUDE VS CABLE LENGTH FOR TWO PLOT TYPES
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      DOUBLE PRECISION OMNAT
      INTEGER TITLE
      REAL X,Y,Z,XSTRT,YSTRT,DELTX,BSCAL
C
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1          ALP(401),S(401),NSEG
      COMMON/C2/A(401),B(401),AMPL(401),PHAS(401),RAMP(401)
      COMMON/C5/STIF(401),STWT(401),OMNAT(401)
      COMMON/PLTINF/IPLTCD,PLEN,IPSPEC,IPSTRT,IPSTOP,TITLE(8)
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     COS(X)     = DCOS(X)
C
C***********************************************************************
C
      DIST = 0.D0
      IF(IPSTRT.EQ.1)GOTO 20
      SSTRT = S(IPSTRT-1)/DELTX
      XSTRT = -(RAMP(IPSTRT)*COS(PHAS(IPSTRT))/BSCAL) + 1.D0
      IF(IPLTCD.EQ.1 .OR. IPLTCD.EQ.3)GOTO 10
      YSTRT = (1.D0-XSTRT)*4.D0 + 4.D0
      IF(AW(IPSTRT-1).LT.1.0D-5)GOTO 4
      CALL SYMBOL(0.,YSTRT,.07,11,0.,-2)
    4 IF(OMNAT(IPSTRT-1).LT.1.0D-5)GOTO 5
      CALL SYMBOL(0.,YSTRT,.07,1,0.,-2)
      GOTO 20
```

```
    5 IF(AW(IPSTRT-1).LT.1.0D-5)CALL SYMBOL(0.,YSTRT,.07,13,0.,-2)
      GOTO 20
   10 IF(AW(IPSTRT-1).LT.1.0D-5)GOTO 14
      CALL SYMBOL(XSTRT,0.,.07,11,0.,-2)
   14 IF(OMNAT(IPSTRT-1).LT.1.0D-5)GOTO 15
      CALL SYMBOL(XSTRT,0.,.07,1,0.,-2)
      GOTO 20
   15 IF(AW(IPSTRT-1).LT.1.0D-5)CALL SYMBOL(XSTRT,0.,.07,13,0.,-2)
C
   20 DO 60 I = IPSTRT,IPSTOP
      SEG = 0.D0
      IF(I.GT.1) DIST = S(I-1)
C
C.....FIND INCREMENT FOR THIS SEGMENT
C
      STEP  = CL(I)/((NZX(I)+1)*7.D0)
   30 SEG   = SEG + STEP
      IF(SEG.GT.CL(I))SEG = CL(I)
      AMPLI = RAMP(I)*COS(SEG * ALP(I)*OMC-PHAS(I))
      X =-(AMPLI/BSCAL) + 1.D0
      IF(IPLTCD.EQ.2 .OR. IPLTCD.EQ.4)Y=(1.D0-X)*4.D0 + 4.D0
      Z = (DIST+SEG)/DELTX
      IF(IPSTRT.GT.1)Z = Z-SSTRT
      IF(IPLTCD.EQ.1 .OR. IPLTCD.EQ.3)Y=Z
      IF(IPLTCD.EQ.2 .OR. IPLTCD.EQ.4)X=Z
      CALL PLOT(X,Y,2)
      IF(SEG.LT.CL(I))GOTO 30
C
C.....END OF SEGMENT DRAW SYMBOL FOR MASS LOCATION
C
      IF(AW(I).LT.1.0D-5)GOTO 40
      CALL SYMBOL(X,Y,.07,11,0.,-2)
   40 IF(OMNAT(I).LT.1.0D-5)GOTO 50
      CALL SYMBOL(X,Y,.07,1,0.,-2)
      GOTO 60
   50 IF(AW(I).LT.1.0D-5)CALL SYMBOL(X,Y,.07,13,0.,-2)
   60 CONTINUE
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE BSCALE(BMAX,BSMANT,IBMLG,BSCAL)
C
C.....SUBROUTINE TO FIND SCALE FOR PLOT USING BMAX
C
C     BSMANT IS THE MANTISSA OF MAXIMUM PLOT ORDINATE
C     IBMLG IS THE POWER OF TEN OF THE MAXIMUM PLOT ORDINATE
C     BSCAL IS THE MAXIMUM PLOT ORDINATE
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      REAL BSMANT,BSCAL
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     AINT(X)    = DINT(X)
C     ALOG10(X)  = DLOG10(X)
C
C***********************************************************************
C
      BMLG  = ALOG10(BMAX)
      IBMLG = BMLG
```

```
      BMRES = BMLG-IBMLG
      IF(IBMLG.LT.0)GOTO 10
      IF(IBMLG.EQ.0 .AND. BMLG.LT.0.D0)GOTO 10
      GOTO 20
   10 IBMLG = IBMLG-1
      BMRES = 1.D0+BMRES
   20 BMANT = 10.D0**BMRES
      BSMANT = AINT(BMANT)+1.D0
      BSCAL = BSMANT*10.D0**IBMLG
C
      RETURN
      END
C
C-------------------------------------------------------------------------
C
      SUBROUTINE CONVRT(X,DIAM,HERTZ,VELFT,VELCM,VELKTS)
C
C.....SUBROUTINE TO CONVERT SEARCH UNITS (RAD/SEC) TO ALTERNATE UNITS.
C
C*************************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C*************************************************************************
C
      COMMON/CONST/PI,STRHN
C
      HERTZ  = X/(2.D0*PI)
      VELFT  = HERTZ/STRHN*(DIAM/12.D0)
      VELCM  = VELFT*30.48D0
      VELKTS = VELFT*0.5921D0
C
      RETURN
      END
C
C-------------------------------------------------------------------------
C
      SUBROUTINE DAMP(NSEG)
C
C.....SUBROUTINE TO SOLVE FOR DAMPING FACTOR
C
C*************************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C*************************************************************************
C
      DOUBLE PRECISION F4,F2,F3,FG,PIM
C
      COMMON/C2/A(401),B(401),AMPL(401),PHAS(401),RAMP(401)
      COMMON/C3/CDC(401),CDA(401),DEFF(401),PRA(401),CD(401),CDAR(401)
      COMMON/C6/F2,F3,F4,FG,PIM
      COMMON/C7/CP(401),DS,ZETA,ZETAE,RHOW,RMU
      COMMON/CONST/PI,STRHN
C
C*************************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     ABS(X)     = DABS(X)
C
C*************************************************************************
C
C.....CALCULATE EFFECTIVE MASS RATIO PARAMETER
C
      RMU = 576.D0*F2/PI/RHOW/DS**2/FG
C
C.....CALCULATE ADDED DAMPING TERM
C
```

```
      ZADDED  = 0.D0
      DO 10 I = 1,NSEG
      ZADDED  = ZADDED +CDA(I)*PRA(I)*ABS(B(I +1)**3)
   10 CONTINUE
      ZADDED  = DS*RHOW*(ZADDED +F3)/18.D0/PI/DSQRT(F2)/DSQRT(F4)
C
C.....FIND STARTING ESTIMATE FOR ZETAE FOR ITERATION
C
      IF(ZADDED.LT.1.0D-15 .AND. ZETA.LT.1.0D-15)GOTO 65
      ZL  = 1.0D-6
   15 FZL = ZL - ZETA - ZADDED/(1.D0 + (9.6D0*(RMU*ZL)**1.8D0))
      IF(FZL.LT.0.D0)GOTO 20
      ZL  = ZL/10.D0
      GOTO 15
   20 ZU  = ZL*10.D0
      FZU = ZU - ZETA - ZADDED/(1.D0 + (9.6D0*(RMU*ZU)**1.8D0))
      IF(FZU*FZL)40,40,30
   30 ZL  = ZU
      FZL = FZU
      GOTO 20
   40 CONTINUE
C
      ZETAE = ZL
C
C.....SEARCH FOR ZETAE (NEWTON-RAPHSON ITERATION SCHEME)
C
      IT = 0
   50 VAR    = (RMU*ZETAE)**1.8D0
      PAR    = 1.0D0 +(9.6D0*VAR)
      DZETA  = 1.0D0  + 17.28D0 *ZADDED*RMU**1.8D0*ZETAE**0.8D0/PAR**2
      FZETA  = ZETAE -ZETA -ZADDED/PAR
      ZETAEN = ZETAE - FZETA/DZETA
      IT = IT +1
      IF(ABS(ZETAEN-ZETAE).LT.1.0D-4) GO TO 70
      IF(IT.LE.100)GOTO 60
      IAPROX = IAPROX+2
      GOTO 70
   60 ZETAE = ZETAEN
      GO TO 50
   65 ZETAEN = 0.D0
   70 ZETAE  = ZETAEN
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE DISDIA
C
C.....FIND NO. OF DISTINCT DIA. AND STORE
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1          ALP(401),S(401),NSEG
      COMMON/DIAM/DU(401),NOD
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     ABS(X)     = DABS(X)
C
C***********************************************************************
C
      K     = 1
```

```
      DU(1) = D(1)
      IF(NSEG.EQ.1)GOTO 30
      DO  20 J = 2,NSEG
      K     = K  + 1
      DU(K) = D(J)
      IL    = J-1
      DO 10 I = 1,IL
      IF(ABS((D(J)-D(I))/D(J)).GT.5.0D-4) GO TO 10
      K     = K - 1
      GO TO 20
   10 CONTINUE
   20 CONTINUE
   30 NOD   = K
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE IMODE(OMC)
C
C.....SUBROUTINE TO EVALUATE INTEGRALS FOR MODE SHAPE FACTOR AND DAMPING
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      DOUBLE PRECISION F4,F2,F3,FG,PIM,AD,BD,DAMPL
C
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1          ALP(401),S(401),NSEG
      COMMON/C2/A(401),B(401),AMPL(401),PHAS(401),RAMP(401)
      COMMON/C3/CDC(401),CDA(401),DEFF(401),PRA(401),CD(401),CDAR(401)
      COMMON/C4/AD(401),BD(401)
      COMMON/C6/F2,F3,F4,FG,PIM
      COMMON/C7/CP(401),DS,ZETA,ZETAE,RHOW,RMU
      COMMON/CONST/PI,STRHN
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     ABS(X)     = DABS(X)
C     AINT(X)    = DINT(X)
C     COS(X)     = DCOS(X)
C     SIN(X)     = DSIN(X)
C
C***********************************************************************
C
      TWO = 2.D0
      THREE = 3.D0
      FOUR = 4.D0
      F4 = 0.D0
      F2 = 0.D0
      F3 = 0.D0
      FG = 0.D0
      DO 100 I=1,NSEG
      ALPO = ALP(I)*OMC
      ARG = ALPO*CL(I)-PHAS(I)
      PAR = ALPO*CL(I)/TWO +(SIN(TWO*ARG) +SIN(TWO*PHAS(I)))/FOUR
      DAMPL = DSQRT(AD(I)*AD(I) + BD(I)*BD(I))
      F4 = F4 +(DAMPL**4*((COS(ARG)**3*SIN(ARG) +COS(PHAS(I))**3*
     1     SIN(PHAS(I)))/FOUR +0.75D0*PAR)/ALPO)*WC(I) +AW(I)*BD(I+1)**4
      F2 = F2 +(DAMPL**2*PAR/ALPO)*WC(I) +AW(I)*BD(I+1)**2
      FG = FG +CP(I)*DAMPL**2*PAR/ALPO
      NPI = ALPO*CL(I)/PI
      EXTRAA = ALPO*CL(I)-NPI*PI
      GAMMA = PHAS(I) +THREE*PI/TWO-PI*AINT((PHAS(I) +THREE*PI/TWO)/PI)
```

```
      TERM1 = SIN(EXTRAA-PHAS(I))*(COS(EXTRAA-PHAS(I))**2 +TWO)
      TERM2 = SIN(PHAS(I))*(COS(PHAS(I))**2+TWO)
      TERM3 = (1.D0-CP(I))*CDC(I)*D(I)*DAMPL**3/36.D0/ALPO
      IF(EXTRAA.GT.GAMMA) GO TO 10
      F3 = F3 +TERM3*(FOUR*NPI +ABS(TERM1 +TERM2))
      GO TO 20
   10 F3 = F3 +TERM3*(FOUR*NPI +ABS(TWO*SIN(GAMMA-PHAS(I))*
     1     (COS(GAMMA-PHAS(I))**2 +TWO) +TERM2-TERM1))
   20 CONTINUE
  100 CONTINUE
      PIM = F4/F2
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE MODPLT(NROOT,NROOTK,DMAX,DMIN,UNITS,JPLTNO)
C
C.....SUBROUTINE TO CONTROL THE PLOTTING OF MODE NUMBER VS FREQUENCY
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      INTEGER UNITS,TITLE
C
      COMMON/DIAM/DU(401),NOD
      COMMON/PLTINF/IPLTCD,PLEN,IPSPEC,IPSTRT,IPSTOP,TITLE(8)
      COMMON/VELPLT/VEL(400),MODNO(100)
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     FLOAT(I)   = DBLE(FLOAT(I))
C     INT(X)     = INT(SNGL(X))
C
C***********************************************************************
C
      IF(IPLTCD.EQ.5)GOTO 10
C
C.....ADVANCES TO NEXT PAGE FOR PAGPLT TYPE PLOTS
C
      NADV = 3-(NROOTK-INT(FLOAT(NROOTK/3 )-0.1)*3)
      ADV  = 2.835*NADV
      CALL PLOT(ADV,0.,-3)
      GOTO 20
   10 CALL PLOTS(53,0,7)
   20 NROOT = NROOT-1
      CALL RANGE(VEL,MODNO,NOD,NROOT,DMAX,DMIN,UNITS)
      JPLTNO = JPLTNO+1
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE NATAUX
C
C.....SUBROUTINE TO CONTROL PROCESSING OF AUXILLIARY DATA FILE
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
```

```
C
      INTEGER TITLE
C
      COMMON/CONST/PI,STRHN
      COMMON/MXAMP/SEGSIR(401),SEGSIZ(401),MXSEG,BSIZE,BPSIZE,BSIZER,
     1             BPSIZR
      COMMON/PLTINF/IPLTCD,PLEN,IPSPEC,IPSTRT,IPSTOP,TITLE(8)
C
      IPSPEC = 1
      JPLTNO = 0
      J = 0
      NROOT = 0
C
C.....READ GENERAL DATA AND PERTINENT SEGMENT DATA
C
      CALL REDAX1(NCOUNT)
C
C.....READ MODAL DATA AND RESPONSE AMPLITUDES AS REQUIRED
C
   10 CALL REDAX2(OMC,MNO,DS,NROOT)
      J = J+1
      VELKTS = OMC*(DS/12.D0)/(2.D0*PI*STRHN)*0.5921D0
      BPSIZR = 0.D0
      DO 20 I = IPSTRT,IPSTOP
      IF(SEGSIR(I).GT.BPSIZR)BPSIZR=SEGSIR(I)
   20 CONTINUE
      CALL PLTCTL(OMC,MNO,DS,VELKTS,NROOT,JPLTNO)
      IF(J.LT.NCOUNT)GOTO 10
C
C.....CLOSE PLOT FILE
C
      CALL PLOT(1.,1.,999)
C
      RETURN
      END
C
C-----------------------------------------------------------------------------
C
      SUBROUTINE PAGPLT(MNO,OMC,IPLTNO,VELKTS,BSMANT,BMLG,BSCAL)
C
C.....ROUTINE TO PLOT OUTPUT IN A PAGEWISE MANNER, MINIMIZING LABELING
C
C*****************************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C*****************************************************************************
C
      INTEGER IHDR1(4),IHDR2(4),TITLE,LABX(2),LABY(2),TITLE2(4),HEAD2(4)
      REAL VELOC,PLEN4,PLEN2,PLEN1,YN,BSMANT,BMLG,DELTX,OMNO
C
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1          ALP(401),S(401),NSEG
      COMMON/PLTINF/IPLTCD,PLEN,IPSPEC,IPSTRT,IPSTOP,TITLE(8)
C
      DATA TITLE2/10HMODE NO.= ,10H     STR V,10HEL=          ,
     1          10HKT,4HS.        /
      DATA HEAD2 /10HRESPONSE A,10HMPLITUDE V,10HS DIST ALO,
     1           10HNG CABLE  /
      DATA LABX  /10HAMPL (IN)*,10H10        /
      DATA LABY  /10HARC LENGTH,10H (FT)     /
C
      IF(IPLTNO.NE.1)GOTO 10
C
C.....WRITE HEADING ONLY ONCE. SUBDIVIDE INTO TWO LINES.
C
      DO 1 I = 1,4
      IHDR1(I) = TITLE(I)
      IHDR2(I) = TITLE(I+4)
```

```
    1 CONTINUE
      CALL PLOT(8.5,0.0,-3)
      CALL SYMBOL(7.50,1.25,.14,IHDR1,90.,40)
      CALL SYMBOL(7.75,1.25,.14,IHDR2,90.,40)
C
C.....DRAW AND LABEL X AXIS OF 2 IN.,MAKING A TIC AT EACH END AND AT CENTER
C
   10 CALL NUMBER(0.,-.35,.07,BSMANT,90.,1)
      CALL SYMBOL(0.,0.,.14,13,0.,-2)
      CALL SYMBOL(1.,0.,.14,13,0.,-2)
      CALL SYMBOL(2.,0.,.14,13,0.,-2)
      CALL NUMBER(1.,-.28,.07,0.0,90.,1)
      CALL NUMBER(2.,-.42,.07,-BSMANT,90.,1)
      CALL SYMBOL(0.54,-0.45,.07,LABX,0.0,12)
      CALL NUMBER(1.38,-0.38,.07,BMLG,0.0,-1)
C
C.....DRAW Y AXIS OF PLEN IN. AND LABEL
C
      IF(PLEN.LT.1.0)PLEN=10.0
      CALL PLOT(1.,0.,3)
      CLNGTH = S(IPSTOP)
      IF(IPSTRT.GT.1)CLNGTH = CLNGTH-S(IPSTRT-1)
      DELTX = CLNGTH/PLEN
      PLEN4 = PLEN
      PLEN1 = PLEN-0.25
      PLEN2 = PLEN/2.0
      CALL SYMBOL(1.,PLEN2,.14,13,90.,-2)
      CALL SYMBOL(1.,PLEN4,.14,13,90.,-2)
      YN    = S(IPSTOP)
      CALL NUMBER(2.,PLEN1,.07,YN,90.,1)
      PLEN1 = PLEN2-0.25
      YN    = YN-CLNGTH/2.0
      CALL NUMBER(2.,PLEN1,.07,YN,90.0,1)
      YN    = S(IPSTOP)-CLNGTH
      CALL NUMBER(2.,0.1,.07,YN,90.0,1)
      PLEN1 = PLEN2-0.55
      CALL SYMBOL(2.25,PLEN1,.07,LABY,90.0,15)
C
C.....CALCULATE AND PLOT AMPLITUDES ALONG THE ENTIRE CABLE SEGMENT BY SEGMENT
C
      CALL PLOT(1.,0.,3)
      CALL AMPLOT(OMC,BSCAL,DELTX)
C
C.....PREPARE FOR AND DRAW HEADING
C
      OMNO  = MNO
      VELOC = VELKTS
      PLEN1 = PLEN2-1.33
      CALL SYMBOL(-0.15,PLEN1,.07,HEAD2,90.,38)
      PLEN1 = PLEN2-1.19
      CALL SYMBOL(0.,PLEN1,.07,TITLE2,90.,34)
      PLEN1 = PLEN2-0.44
      CALL NUMBER(0.,PLEN1,.07,OMNO,90.,-1)
      PLEN1 = PLEN2 + 0.49
      CALL NUMBER(0.,PLEN1,.07,VELOC,90.,2)
C
C.....ADVANCING PLOT
C
      CALL PLOT(2.515,-0.65,-3)
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE PLTCTL(OMC,MNO,DS,VELKTS,NROOT,JPLTNO)
C
C.....SUBROUTINE TO CONTROL PLOTTING PROCEDURE
C
C***********************************************************************
```

```
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C**************************************************************************
C
      INTEGER TITLE
      REAL BSMANT,BSCAL,BMLG
C
      COMMON/MXAMP/SEGSIR(401),SEGSIZ(401),MXSEG,BSIZE,BPSIZE,BSIZER,
     1             BPSIZR
      COMMON/PLTINF/IPLTCD,PLEN,IPSPEC,IPSTRT,IPSTOP,TITLE(8)
C
      IF(JPLTNO.EQ.0)CALL PLOTS(53,0,7)
      IF(JPLTNO.GT.0.AND.NROOT.EQ.1)CALL PLOT(1.5,0.,-3)
      CALL PLOT(.32,.65,-3)
C
C.....FIND MAXIMUM AMPLITUDE AND SCALING FACTOR FOR PLOT.
C
      IF(IPSPEC.EQ.1)BSIZER = BPSIZR
      CALL BSCALE(BSIZER,BSMANT,IBMLG,BSCAL)
C
      BMLG = FLOAT(IBMLG)
      IF(IPLTCD.EQ.1 .OR. IPLTCD.EQ.3)GOTO 10
      CALL SCROLL(MNO,OMC,DS,VELKTS,BSMANT,BMLG,BSCAL)
      JPLTNO = JPLTNO+1
      RETURN
C
   10 CALL PAGPLT(MNO,OMC,NROOT,VELKTS,BSMANT,BMLG,BSCAL)
      JPLTNO = JPLTNO+1
C
      RETURN
      END
C
C-------------------------------------------------------------------------
C
      SUBROUTINE RANGE(VEL,MODNO,NPTS,NCURVS,DMAX,DMIN,UNITS)
C
C.....SUBROUTINE TO PLOT MODE NO. VS. STROUHAL VELOCITY
C
C**************************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     DOUBLE PRECISION OMSTRT,OMSTOP,DMIN,DMAX,PI,STRHN,DU
C
C**************************************************************************
C
      INTEGER LABELX(2),LABELY(2),IA(4),IB(4),LABX2(1),SYM(2),TITLE,
     1          TITL2(4),UNITS
C
      COMMON/CONST/PI,STRHN
      COMMON/DIAM/DU(401),NOD
      COMMON/MODE/MXMDS,OMSTRT,OMSTOP,DELOM,ACC,ITCT,IAPROX,IBCODE
      COMMON/PLTINF/IPLTCD,PLEN,IPSPEC,IPSTRT,IPSTOP,TITLE(8)
      DIMENSION VEL(1),MODNO(1)
C
      DATA LABELX/10HVELOCITY (,10H       )  /,
     1     LABELY/10HMODE NUMBE,10HR         /,
     2     NCHARX,NCHARY,NA,NB/17,11,40,40/,
     3     LABX2/10H KTS.     /,NCHX2/6/,
     4     SYM/10HSYMBOL  SH,10HED. DIA   /,NSYM/17/,
     5     TITL2/10HMODE NUMBE,10HR VS. STRO,10HUHAL VELOC,
     6          10HITY       /,NTITL2/33/
C
      XLWLFT  = .875
      YLWLFT  = .625
      XLNGTH  = 9.
      YLNGTH  = 7.
      NC      = NPTS*NCURVS
      NC1     = NC + 1
```

```
      NC2    = NC + 2
      XORIG  = 8.25 - (YLNGTH + YLWLFT)
      YORIG  = 0.25 + XLWLFT
C
C.....CALCULATE ABSCISSA LIMITS AND DRAW AXIS
C
      CALL PLOT(XORIG,YORIG,-3)
      IF(UNITS.GT.2)GOTO 10
      XSTRT = OMSTRT*(DMIN/12.)/(2.*PI*STRHN)*0.5921
      XSTOP = OMSTOP*(DMAX/12.)/(2.*PI*STRHN)*0.5921
      GOTO 30
   10 XSTRT = OMSTRT*(DMAX/12.)/(2.*PI*STRHN)
      XSTOP = OMSTOP*(DMIN/12.)/(2.*PI*STRHN)
      IF(UNITS.EQ.5)GOTO 20
      LABX2 = 10HFT/SEC
      IF(UNITS.EQ.3)GOTO 30
      XSTRT = XSTRT*30.48
      XSTOP = XSTOP*30.48
      LABX2 = 10HCM/SEC
      GOTO 30
   20 XSTRT = XSTRT*0.5921
      XSTOP = XSTOP*0.5921
   30 VEL(NC1) = XSTRT
      VEL(NC2) = (XSTOP-XSTRT)/(XLNGTH)
      CALL AXIS(YLNGTH,0.0,LABELX,-NCHARX,XLNGTH,90.0,VEL(NC1),VEL(NC2))
      XLNGT2 = XLNGTH/2. +.28
      YLNGT2 = YLNGTH + .42
      CALL SYMBOL(YLNGT2,XLNGT2,.14,LABX2,90.,NCHX2)
C
C.....PLOT ORDINATE AXIS
C
      CALL PLOT(0.,0.,3)
      X = 0.0
      DO 35 I = 1,6
      X = X + 1.0
      CALL SYMBOL(X,0.,.07,15,90.,-2)
   35 CONTINUE
      CALL PLOT(7.,0.,2)
      YLNGT3 = YLNGTH/2.-0.84
      CALL SYMBOL(YLNGT3,-0.56,0.14,LABELY,0.,NCHARY)
      MM = INT((FLOAT(NCURVS)-.05)/(YLNGTH-2.))
      MODNO(NCURVS+2) = -FLOAT(MM+1)
      MODNO(NCURVS+1) = MODNO(1) - MODNO(NCURVS+2)*INT(YLNGTH-2.0)
      POS    = YLNGTH
      NYLNGT = YLNGTH-1.0
      DO 40 I = 1,NYLNGT
      POS  = POS -1.
      FMNO = FLOAT(MODNO(1) + (MM+1)*(I-1))
      CALL NUMBER(POS,-.35,.105,FMNO,90.,-1)
   40 CONTINUE
C
C.....COMPLETE ENCLOSING BOX
C
      CALL PLOT(0.,0.,3)
      Y = 0.0
      DO 44 I = 1,8
      Y = Y + 1.0
      CALL SYMBOL(0.,Y,.07,15,0.,-2)
   44 CONTINUE
      CALL PLOT(0.,9.,2)
      X = 0.0
      DO 45 I = 1,6
      X = X + 1.0
      CALL SYMBOL(X,9.,.07,15,-90.,-2)
   45 CONTINUE
      CALL PLOT(7.,9.,2)
C
C.....PLOT POINTS
C
      DO 60 I = 1,NCURVS
```

```
      DO 50 J = 1,NPTS
      Y  = FLOAT(MODNO(NCURVS+1)-MODNO(I))/FLOAT(-MODNO(NCURVS+2))+1.0
      X  = (VEL(J+(I-1)*NPTS)-XSTRT)/(XSTOP-XSTRT)*XLNGTH
      J1 = J-1
      CALL SYMBOL(Y,X,.105,J1,90.,-1)
   50 CONTINUE
   60 CONTINUE
C
C.....WRITE HEADING. SUBDIVIDE INTO TWO LINES.
C
      DO 70 I = 1,4
      IA(I) = TITLE(I)
      IB(I) = TITLE(I+4)
   70 CONTINUE
      STRT = XLNGTH/2. - 2.1
      CALL SYMBOL(.5,STRT,.105,IA,90.,NA)
      CALL SYMBOL(.75,STRT,.105,IB,90.,NB)
      STRT = STRT - 0.15
      CALL SYMBOL(.25,STRT,.14,TITL2,90.,NTITL2)
C
C.....DRAW AND FILL KEY TO SYMBOLS
C
      XLN1 = XLNGTH - 1.0
      XLN2 = XLN1 - 1.0
      YLN2 = YLNGTH - 1.0
      XLN4 = XLN2 + 0.185
      YLN4 = YLN2 + 0.14
      XLN5 = XLN1 - 0.5
      YLN5 = YLN4 + .035
      XLN6 = XLN5 + 0.71
      YLN6 = YLN5 - 0.0525
      CALL PLOT(YLNGTH,XLN2,3)
      CALL PLOT(YLN2,XLN2,2)
      CALL PLOT(YLN2,XLNGTH,2)
      CALL PLOT(YLN2,XLN1,3)
      CALL PLOT(YLNGTH,XLN1,2)
      CALL SYMBOL(YLN4,XLN4,.105,SYM,90.,NSYM)
      CALL PLOT(YLN5,XLNGTH,3)
      CALL PLOT(YLN5,XLN2,2)
      DO 80 I = 1,NPTS
      I1   = I-1
      YLN6 = YLN6 + 0.14
      YLN7 = YLN6 + 0.0525
      DIAM = DU(I)
      CALL SYMBOL(YLN6,XLN5,.105,I1,90.,-1)
      CALL NUMBER(YLN7,XLN6,.105,DIAM,90.,5)
   80 CONTINUE
C
      XORIG = 8.5 - XORIG
      CALL PLOT(XORIG,-YORIG,-3)
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE READ(UNITS,DMAX,DMIN,IAUX,NMASS)
C
C.....SUBROUTINE TO READ/WRITE INPUT DATA
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      DOUBLE PRECISION OMNAT
      INTEGER TITLE,BCOND(1),UNITS
      REAL KMSTRT,KMSTOP,KDELOM
C
```

```
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1         ALP(401),S(401),NSEG
      COMMON/C3/CDC(401),CDA(401),DEFF(401),PRA(401),CD(401),CDAR(401)
      COMMON/C5/STIF(401),STWT(401),OMNAT(401)
      COMMON/C7/CP(401),DS,ZETA,ZETAE,RHOW,RMU
      COMMON/C8/CPRA,PRASUM,CDT,CDTOT,CDWT,CDCAV,CDAAV
      COMMON/CONST/PI,STRHN
      COMMON/DEVICE/IIN,IOUT,IADF
      COMMON/MODE/MXMDS,OMSTRT,OMSTOP,DELOM,ACC,ITCT,IAPROX,IBCODE
      COMMON/OUTLOC/SPLOC(401),IOUTCD,NSPEC
      COMMON/PLTINF/IPLTCD,PLEN,IPSPEC,IPSTRT,IPSTOP,TITLE(8)
C
C*************************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     SQRT(X)    = DSQRT(X)
C
C*************************************************************************
C
C.....READ GENERAL INFORMATION
C
      READ(IIN,1001)NSEG,IBCODE,ZETA,RHOW
 1001 FORMAT(2I5,2F10.0)
      IF(RHOW.LT.1.0D-6) RHOW = 64.0D0
C
C.....READ CABLE SEGMENT LENGTHS
C
      J = 0
      DO 101 I = 1,NSEG
      IF(I.LE.J)GOTO 101
      READ(IIN,1002)CL(I),KG
 1002 FORMAT(F10.0,I5)
      IF(KG.LE.1)GO TO 101
C
C.....GENERATE REPEATED SEGMENT DATA
C
      I1 = I+1
      IKG1 = I+KG-1
      DO 102 J = I1,IKG1
      IF(J.GT.NSEG)GO TO 200
      CL(J) = CL(I)
  102 CONTINUE
  101 CONTINUE
C
C.....READ SEGMENT PROPERTY VALUES (DIAMETERS, DRAG COEFF, ETC.)
C
      J = 0
      DO 103 I = 1,NSEG
      IF(I.LE.J)GOTO 103
      READ(IIN,1003) D(I),WC(I),TC(I),CDC(I),KG
 1003 FORMAT(4F10.0,I5)
C     IF(CDC(I).LT.1.0D-6)CDC(I)=1.D0
      IF(KG.LE.1)GO TO 103
C
C.....GENERATE REPEATED SEGMENT DATA
C
      I1 = I+1
      IKG1 = I+KG-1
      DO 104 J = I1,IKG1
      IF(J.GT.NSEG)GO TO 200
      D(J) = D(I)
      CDC(J) = CDC(I)
      WC(J) = WC(I)
      TC(J) = TC(I)
  104 CONTINUE
  103 CONTINUE
C
C.....READ ADDED MASS/SPRUNG MASS INFORMATION
C
      J = 0
```

```
      DO 105 I = 1,NSEG
      IF(I.LE.J)GOTO 105
      READ(IIN,1004)AW(I),STIF(I),STWT(I),CDA(I),PRA(I),DEFF(I),KG
 1004 FORMAT(6F10.0,I5)
C     IF(CDA(I).LT.1.0D-6)CDA(I)=1.D0
      IF(DEFF(I).LT.1.0D-6) DEFF(I)=D(I)
      IF(KG.LE.1)GO TO 105
C
C.....GENERATE REPEATED SEGMENT DATA
C
      I1 = I+1
      IKG1 = I+KG-1
      DO 106 J = I1,IKG1
      IF(J.GT.NSEG)GO TO 200
      AW(J)   = AW(I)
      CDA(J)  = CDA(I)
      STIF(J) = STIF(I)
      STWT(J) = STWT(I)
      DEFF(J) = DEFF(I)
      PRA(J)  = PRA(I)
  106 CONTINUE
  105 CONTINUE
C
C.....READ FREQUENCY SEARCH PARAMETERS, FLUID DAMPING AND DENSITY
C
      READ(IIN,1005)MXMDS,OMSTRT,OMSTOP,DELOM,ACC,UNITS
 1005 FORMAT(I10,4F10.0,I5)
C
C.....READ OUTPUT CONTROL INFORMATION
C
      READ(IIN,1006)IAUX,IOUTCD,NSPEC
 1006 FORMAT(3I5)
      IF(IOUTCD.EQ.0)GOTO 110
      IF(IOUTCD.EQ.2 .OR. IOUTCD.EQ.4)GOTO 110
      READ(IIN,1007)(SPLOC(I),I=1,NSPEC)
 1007 FORMAT(8F10.0)
C
C.....READ PLOTTING CONTROL INFORMATION
C
  110 READ(IIN,1008)IPLTCD,IPSPEC,PLEN
 1008 FORMAT(2I5,F10.0)
      IF(IPSPEC.EQ.0)GOTO 115
      READ (5,1009) IPSTRT,IPSTOP
 1009 FORMAT(2I5)
C
C.....WRITE OUT CABLE PARAMETERS
C
  115 NMASS = 0
      AWT    = 0.D0
      CPRA   = 0.D0
      PRASUM = 0.D0
      CDCAV  = 0.D0
      CDAAV  = 0.D0
      SARC   = 0.D0
      DMAX   = 0.D0
      TMIN   = TC(1)
      WMAX   = WC(1)
      IF(IBCODE.EQ.1)GOTO 120
      AW(NSEG)   = 0.D0
      CDA(NSEG)  = 0.D0
      STIF(NSEG) = 0.D0
      STWT(NSEG) = 0.D0
  120 DO 125 I = 1,NSEG
      IF(AW(I).GT.1.0D-6)NMASS = NMASS+1
      IF(AW(I).LE.1.0D-6)CDA(I) = 0.D0
      CPRA   = CPRA + CL(I)*(D(I)/12.D0)
      PRASUM = PRASUM + PRA(I)
      CDAAV  = CDAAV + CDA(I)*PRA(I)
      CDCAV  = CDCAV + CDC(I)*CL(I)*(D(I)/12.D0)
      S(I)   = 0.D0
```

```
      SARC   = SARC+CL(I)
      S(I)   = SARC
      OMNAT(I) = 0.D0
      G       = 32.2D0
      IF(STWT(I).GT.1.0D-6)OMNAT(I) = SQRT(STIF(I)*G/STWT(I))
      WRITE(IOUT,2001)I,CL(I),S(I),D(I),CDC(I),WC(I),TC(I),AW(I),CDA(I),
     1               PRA(I),DEFF(I),STIF(I),STWT(I)
 2001 FORMAT(1X,I3,3X,0PF8.3,1X,0PF10.3,2X,1PE10.3,2X,0PF5.2,2X,1PE10.3,
     1      3X,0PF7.2,2X,1PE10.3,2X,0PF5.2,2(2X,1PE10.3),2(2X,0PF7.2))
C
C.....CALCULATE ALPHA(I),S(NSEG),AWT,TMIN,WMAX
C
      AWT    = AWT   + AW(I) +STWT(I)
      ALP(I) = SQRT(WC(I)/G/TC(I))
      IF (TC(I) .LT. TMIN) TMIN = TC(I)
      IF (WC(I) .GT. WMAX) WMAX = WC(I)
      IF (D(I) .GT. DMAX) DMAX = D(I)
      IF (I .EQ. 1) DMIN = DMAX
      IF (D(I) .LT. DMIN) DMIN = D(I)
  125 CONTINUE
      IF (AWT/S(NSEG) .GT. WMAX) WMAX = AWT/S(NSEG)
      WRITE(IOUT,2002) NSEG
 2002 FORMAT (/" TOTAL NO OF SEGMENTS = ",I3)
C
C.....CALCULATE INITIAL AVERAGE DRAG VALUES
C
      CDCAV = CDCAV/CPRA
      IF(PRASUM.EQ.0)GOTO 126
      CDAAV = CDAAV/PRASUM
  126 WRITE(IOUT,2003)CDCAV,CPRA
 2003 FORMAT(/" AVERAGE CABLE DRAG COEF = ",0PF9.3," BASED ON PROJECTED
     1CABLE AREA OF ",1PE10.3," (FT**2)")
      WRITE(IOUT,2004)CDAAV,NMASS,PRASUM
 2004 FORMAT(/" AVERAGE MASS DRAG COEF  = ",0PF9.3," OVER",I4,
     1 " MASSES AND PROJECTED AREA OF",1PE10.3," (FT**2)")
C
C.....CHANGE FROM INPUT SEARCH UNITS TO RAD/SEC
C
      CALL UNIT (OMSTRT,OMSTOP,DELOM,UNITS,DMAX,DMIN)
C
C.....SET DEFAULT ACCURACY TO 0.005 PERCENT.
C
      IF (ACC.LT.1.0D-6)ACC = 5.0D-5
      IF (OMSTRT.LT.1.0D-10)OMSTRT = 1.0D-10
C
C.....CALCULATE DELOM - FREQUENCY SEARCH INCREMENT
C
      IF(DELOM.GT.1.0D-10) GO TO 130
      DELOM = SQRT(TMIN*G/WMAX)/S(NSEG)/20.D0
C
C.....WRITE FREQUENCY SEARCH INFORMATION
C
  130 WRITE(IOUT,2005) MXMDS
 2005 FORMAT (/" MAXIMUM NO OF MODES SOUGHT = ",I3)
      BCOND = 10HFIXED
      IF(IBCODE.EQ.0)GOTO 135
      BCOND = 10HFREE
  135 WRITE(IOUT,2006)BCOND
 2006 FORMAT(/" BOUNDARY CONDITION AT END OF LAST SEGMENT : ",A10,//
     1 15X," MODE SEARCH LIMITS"/11X," LOWER",4X," UPPER"/
     2 11X," LIMIT",4X," LIMIT",2X," INCREMENT")
C
C.....WRITE SEARCH PARAMETERS IN VARIOUS UNITS
C
      CALL CONVRT(OMSTRT,DMIN,HMSTRT,FMSTRT,CMSTRT,KMSTRT)
      CALL CONVRT(OMSTOP,DMAX,HMSTOP,FMSTOP,CMSTOP,KMSTOP)
      CALL CONVRT(DELOM,DMAX,HDELOM,FDELOM,CDELOM,KDELOM)
      WRITE(IOUT,2007) KMSTRT,KMSTOP,KDELOM,HMSTRT,HMSTOP,HDELOM,
     1               FMSTRT,FMSTOP,FDELOM,CMSTRT,CMSTOP,CDELOM,
     2               OMSTRT,OMSTOP,DELOM
```

```
 2007 FORMAT("   KNOTS",3F10.4,/,"   HERTZ",3F10.4,/,"  FT/SEC",3F10.4,/,
     1        "  CM/SEC",3F10.4,/," RAD/SEC",3F10.4)
C
C.....WRITE INITIAL CABLE DAMPING COEF. AND FLUID DENSITY
C
      WRITE(IOUT,2008)ZETA,RHOW
 2008 FORMAT(//" FRACTION OF STRUCTURAL CRITICAL DAMPING IN AIR = ",
     1 F7.4//" FLUID DENSITY = ",1PE10.3," (LB/FT*3)",/)
C
C.....MODIFY DAMPING FACTOR FOR FLUID EFFECTS
C
      TOTMAS = 0.D0
      TOTWAT = 0.D0
      DO 140 I = 1,NSEG
      TOTMAS = TOTMAS+WC(I)*CL(I)
      TOTWAT = TOTWAT+D(I)*D(I)*CL(I)/144.D0
  140 CONTINUE
      AVEDEN = TOTMAS/S(NSEG)
      AVEWAT = TOTWAT*PI/4.D0*RHOW/S(NSEG)
      ZETA   = ZETA*SQRT((AVEDEN-AVEWAT)/AVEDEN)
      WRITE(IOUT,2009)ZETA
 2009 FORMAT(//" FRACTION OF STRUCTURAL CRITICAL DAMPING IN FLUID = ",
     1 F7.4)
      WRITE(IOUT,2010)
 2010 FORMAT(1H1)
      GOTO 999
C
C.....ERROR MESSAGE IF TOO MANY SEGMENTS GENERATED
C
  200 WRITE(IOUT,2011)
 2011 FORMAT(////10X,57(1H*)/10X,"CHECK INPUT DATA. NO. OF SEGMENTS",
     1          " GENERATED EXCEEDS NSEG."/10X,57(1H*))
      STOP
C
  999 CONTINUE
      RETURN
      END
C
C---------------------------------------------------------------------------
C
      SUBROUTINE REDAX1(NCOUNT)
C
C.....SUBROUTINE TO READ GENERAL INFO AND SEGMENT DATA FROM AUX. DATA FILE
C
C****************************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C****************************************************************************
C
      INTEGER TITLE
C
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1          ALP(401),S(401),NSEG
      COMMON/DEVICE/IIN,IOUT,IADF
      COMMON/PLTINF/IPLTCD,PLEN,IPSPEC,IPSTRT,IPSTOP,TITLE(8)
C
C.....READ GENERAL INFO.
C
      READ(IIN,1001)NSEG,IPLTCD,PLEN,NCOUNT
 1001 FORMAT(/I5,5X,I5,4X,F6.0,6X,I3)
      READ(IIN,1002)
 1002 FORMAT()
      DO 10 I = 1,NSEG
      READ(IIN,1003)CL(I),S(I),D(I),ALP(I),AW(I)
 1003 FORMAT(5X,5(5X,1PE10.3))
   10 CONTINUE
C
      RETURN
```

```
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE REDAX2(OMC,MNO,DS,NROOT)
C
C.....SUBROUTINE TO READ MODAL DATA AND RESPONSE AMPLITUDES
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      INTEGER TITLE
C
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1          ALP(401),S(401),NSEG
      COMMON/C2/A(401),B(401),AMPL(401),PHAS(401),RAMP(401)
      COMMON/DEVICE/IIN,IOUT,IADF
      COMMON/MXAMP/SEGSIR(401),SEGSIZ(401),MXSEG,BSIZE,BPSIZE,BSIZER,
     1             BPSIZR
      COMMON/PLTINF/IPLTCD,PLEN,IPSPEC,IPSTRT,IPSTOP,TITLE(8)
C
   10 READ(IIN,1001)NUMBER
 1001 FORMAT(I5)
      IF(NUMBER.GT.0)GOTO 50
      READ(IIN,1002)MNO,OMC
 1002 FORMAT(10X,I5,20X,1PE10.3)
      READ(IIN,1003)IPSTRT,IPSTOP
 1003 FORMAT(/2(I5,10X))
      IF(IPSTRT.EQ.0)IPSTRT=1
      IF(IPSTOP.EQ.0)IPSTOP=NSEG
      DO 20 I = 1,IPSTRT
      READ(IIN,1004)
 1004 FORMAT()
   20 CONTINUE
      DO 30 I = IPSTRT,IPSTOP
      READ(IIN,1005)PHAS(I),NZX(I)
 1005 FORMAT(10X,1PE10.3,50X,I5)
   30 CONTINUE
      IPSTP1 = IPSTOP+1
      NSEG1 = NSEG + 1
      DO 40 I = IPSTP1,NSEG1
      READ(IIN,1004)
   40 CONTINUE
      READ(IIN,1004)
      NROOT = NROOT+1
C
   50 READ(IIN,1006)DS
 1006 FORMAT(20X,1PE10.3)
      DO 60 I = 1,IPSTRT
      READ(IIN,1004)
   60 CONTINUE
      DO 70 I = IPSTRT,IPSTOP
      READ(IIN,1007)RAMP(I),SEGSIR(I)
 1007 FORMAT(5X,2(5X,1PE10.3))
   70 CONTINUE
      IF(IPSTOP.EQ.NSEG)GOTO 90
      DO 80 I = IPSTP1,NSEG
      READ(IIN,1004)
   80 CONTINUE
C
   90 CONTINUE
      RETURN
      END
C
C-----------------------------------------------------------------------
C
```

```
      SUBROUTINE RESAMP(NSEG)
C
C.....SUBROUTINE TO MODIFY MODAL AMPLITUDE TO RESPONSE AMPLITUDE
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      DOUBLE PRECISION F2,F4,FG,F3,PIM
C
      COMMON/C2/A(401),B(401),AMPL(401),PHAS(401),RAMP(401)
      COMMON/C6/F2,F3,F4,FG,PIM
      COMMON/C7/CP(401),DS,ZETA,ZETAE,RHOW,RMU
      COMMON/MODE/MXMDS,OMSTRT,OMSTOP,DELOM,ACC,ITCT,IAPROX,IBCODE
      COMMON/MXAMP/SEGSIR(401),SEGSIZ(401),MXSEG,BSIZE,BPSIZE,BSIZER,
     1             BPSIZR
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     ABS(X)     = DABS(X)
C     SQRT(X)    = DSQRT(X)
C
C***********************************************************************
C
      AMAX       = 1.D0/(1.D0+9.6D0*(RMU*ZETAE)**1.8D0)
      CONS       = AMAX*DS/DSQRT(PIM)
      DO 10 I=1,NSEG
      RAMP(I)    = CONS*AMPL(I)
      A(I)       = ABS(CONS*B(I))
      SEGSIR(I)  = CONS*SEGSIZ(I)
   10 CONTINUE
      BSIZER     = ABS(CONS*BSIZE)
      BPSIZR     = ABS(CONS*BPSIZE)
      A(NSEG+1)  = ABS(CONS*B(NSEG+1))
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE SCROLL(MNO,OMC,DS,VELKTS,BSMANT,BMLG,BSCAL)
C
C.....ROUTINE TO PLOT AMPLITUDE VS. DISTANCE ALONG CABLE
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      INTEGER LABLX(2),LABLY(3),DESCR(8),HEAD2(4),SEGNO(3),TITLE
      REAL VELOC,DIA,HOMC,OMNO,BSMANT,BSMAN4,BMLG,LNGTH,X,PSTRT,PSTOP,
     1      DELTX,ADV
C
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1          ALP(401),S(401),NSEG
      COMMON/CONST/PI,STRHN
      COMMON/PLTINF/IPLTCD,PLEN,IPSPEC,IPSTRT,IPSTOP,TITLE(8)
C
      DATA LABLY/10HAMPLITUDE ,10H (INCHES) ,10H(*10 )    /
      DATA LABLX/10HARC LENGTH,10H  (FEET)  /
      DATA HEAD2/10HRESPONSE A,10HMPLITUDE V,10HS DIST ALO,
     1          10HNG CABLE  /
      DATA DESCR/10HMODE NO.= ,10H     FREQU,10HENCY=     ,
     1          10H HZ.  SHE,10HD. DIAM=  ,10H     IN.  ,
```

```
     2            10HSTR VEL=   ,10H     KTS. /
      DATA SEGNO/10HPLOT RANGE,10H: SEGMENTS,10H     TO   /
C
      CALL PLOT(.98,.65,-3)
C
C.....PLOT VERTICAL AXIS AND LABEL
C
      BSMAN4 = BSMANT/4.
      CALL AXIS(0.,0.,LABLY,26,8.,90.,-BSMANT,BSMAN4)
      CALL NUMBER(-.38,5.55,.07,BMLG,90.,-1)
      CALL PLOT(0.,4.,3)
C
C.....CHECK FOR PLEN = 0, IF SO, SET TO 20.
C
      IF(PLEN.LT.1.D0)PLEN = 20.D0
      LNGTH = PLEN
C
C.....DRAW HORIZONTAL LINE THE LENGTH SPECIFIED ON INPUT, TICS EVERY INCH
C
      CALL PLOT(0.,4.,3)
      X = 0.0
      NOTICS = INT(LNGTH)
      DO 10 I = 1,NOTICS
      X = X + 1.0
      CALL SYMBOL(X,4.,.14,13,0.,-2)
   10 CONTINUE
C
C.....DRAW ANOTHER HORIZONTAL LINE TO BE LABELED WITH UNITS
C
      CLNGTH = S(IPSTOP)
      IF(IPSTRT.GT.1)CLNGTH = CLNGTH-S(IPSTRT-1)
      DELTX = CLNGTH/PLEN
      CALL AXIS(0.,0.,LABLX,-20,LNGTH,0.,0.,DELTX)
C
C.....CALCULATE AND PLOT AMPLITUDES ALONG THE ENTIRE CABLE SEGMENT BY SEGMENT
C
      CALL PLOT(0.,4.,3)
      CALL AMPLOT(OMC,BSCAL,DELTX)
C
C.....PREPARE FOR AND DRAW HEADINGS
C
      HOMC  = OMC/(2.D0*PI)
      OMNO  = MNO
      VELOC = VELKTS
      DIA   = DS
      PSTRT = IPSTRT
      PSTOP = IPSTOP
      CALL PLOT(0.,8.,3)
      X = PLEN/2 - 5.5
      CALL SYMBOL(X,8.7,.14,TITLE,0.,80)
      X = X + 2.84
      CALL SYMBOL(X,8.95,.14,HEAD2,0.,38)
      X = X - 2.84
      CALL SYMBOL(X,8.45,.14,DESCR,0.,79)
      X = X + 3.33
      CALL SYMBOL(X,8.2,.14,SEGNO,0.,28)
      X = X - 2.07
      CALL NUMBER(X,8.45,.14,OMNO,0.,-1)
      X = X + 2.24
      CALL NUMBER(X,8.45,.14,HOMC,0.,4)
      X = X + 3.22
      CALL NUMBER(X,8.45,.14,DIA,0.,4)
      X = X + 2.80
      CALL NUMBER(X,8.45,.14,VELOC,0.,4)
      X = X - 3.25
      CALL NUMBER(X,8.2,.14,PSTRT,0.,-1)
      X = X + 0.98
      CALL NUMBER(X,8.2,.14,PSTOP,0.,-1)
C
C.....ADVANCE THE PLOT
```

```
C
      ADV = PLEN + 2.5
      CALL PLOT(ADV,-1.3,-3)
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE SEARCH(NSEG,OMC,BX)
C
C.....SUBROUTINE TO SEARCH FOR NATURAL FREQUENCIES
C
      DOUBLE PRECISION OMCD,OMP,X1,X2,B1,B2,BP,BC,AD,BD,DELW,DELW1,
     1                 BCPREV,BX
C
      COMMON/C4/AD(401),BD(401)
      COMMON/MODE/MXMDS,OMSTRT,OMSTOP,DELOM,ACC,ITCT,IAPROX,IBCODE
      COMMON/MXAMP/SEGSIR(401),SEGSIZ(401),MXSEG,BSIZE,BPSIZE,BSIZER,
     1            BPSIZR
      COMMON/SRCPAR/OMCD,OMP,BP,B2,X2,ISERCH
C
      ITCT = 0
   10 CALL SOLV(OMCD)
      BCPREV = BC
      BC     = BD(NSEG  + 1)
      IF(IBCODE.EQ.1)BC = AD(NSEG+1)
      BX = BC/BSIZE*100.D0
      IF (DABS(BX/100.D0).LE.ACC)GO TO 100
      IF(ITCT.EQ.0)GOTO 20
      IF(DABS((BC-BCPREV)/BCPREV).LT.1.0D-12)GOTO 100
      GOTO 60
   20 IF(ISERCH.NE.0) GO TO 30
      BP = BC
      ISERCH = 1
   30 IF(BC*BP)50,50,40
   40 OMP  = OMCD
      BP   = BC
      OMCD = OMCD + DELOM
      GO TO 10
   50 B1 = BP
      B2 = BC
      X1 = OMP
      X2 = OMCD
   60 ITCT = ITCT  +1
      IF (ITCT.GT.100)GO TO 90
      IF(B1*BC.LE.0.D0) GO TO 70
      B1 = BC
      X1 = OMCD
      GO TO 80
   70 B2 = BC
      X2 = OMCD
   80 DELW  = (X2-X1)*B1/(B2-B1)
      DELW1 = DELW/OMCD
      IF(DABS(DELW1).LT.1.0D-14)GO TO 100
      OMCD  = X1 - DELW
      GO TO 10
C
C.....NATURAL FREQUENCY FOUND OR SEARCH TERMINATED IF NO CONVERGENCE
C
   90 IAPROX = 1
  100 CONTINUE
      OMC = OMCD
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE SEGDRG(OMC)
```

```
C
C.....SUBROUTINE TO CALCULATE AVERAGE DRAG ON CABLE SEGMENT, ALLOWING
C.....FOR DRAG AMPLITUDE VARIATION ALONG SEGMENT LENGTH
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1          ALP(401),S(401),NSEG
      COMMON/C2/A(401),B(401),AMPL(401),PHAS(401),RAMP(401)
      COMMON/C3/CDC(401),CDA(401),DEFF(401),PRA(401),CD(401),CDAR(401)
      COMMON/CONST/PI,STRHN
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     INT(X)      = INT(SNGL(X))
C
C***********************************************************************
C
      DO 100 I = 1,NSEG
      R1  = -1.D0 * PHAS(I)
      PAR = ALP(I) * OMC * CL(I)
      R2  = PAR  + R1 -  INT(PAR/PI)*PI
C
      CALL SIMP(R1,R2,20,AREA)
C
      CD(I) = (1.D0+ 1.82024D0*(RAMP(I)/D(I))**.65D0*(INT(PAR/PI)*
     1         2.2546D0 + AREA)/PAR)*CDC(I)
  100 CONTINUE
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE SIMP(R1,R2,N,AREA)
C
C.....SUBROUTINE TO INTEGRATE FUNCTION F(X) BY SIMPSON'S RULE
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C     ABS(X)      = DABS(X)
C     COS(X)      = DCOS(X)
C
C***********************************************************************
C
      F(X) = (ABS(COS(X)))**0.65D0
      TWO  = 2.D0
      DX   = (R2-R1)/TWO/N
      AREA = 0.D0
      X    = R1
      DO 100 I = 1,N
      AREA = AREA  + (DX/3.D0)*(F(X) +4.D0*F(X+DX)+F(X+TWO*DX))
      X = X  + TWO*DX
  100 CONTINUE
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE STORE(OMC,MNO,NROOT,DS,UNITS,K)
```

```
C
C.....SUBROUTINE TO STORE MODE NUMBERS AND FREQUENCIES FOR PLOTTING
C
C***************************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***************************************************************************
C
      REAL VEL
      INTEGER UNITS
C
      COMMON/CONST/PI,STRHN
      COMMON/DIAM/DU(401),NOD
      COMMON/VELPLT/VEL(400),MODNO(100)
C
      IF(UNITS.LE.2 .OR. UNITS.EQ.5)VEL((NROOT-1)*NOD+K) = OMC*
     1                       (DS/12.D0)/(2.D0*PI*STRHN) *0.5921D0
      IF(UNITS.EQ.3)VEL((NROOT-1)*NOD+K) = OMC*
     1              (DS/12.D0)/(2.D0*PI*STRHN)
      IF(UNITS.EQ.4)VEL((NROOT-1)*NOD+K) = OMC*
     1              (DS/12.D0)/(2.D0*PI*STRHN) *30.48D0
      MODNO(NROOT) = MNO
C
      RETURN
      END
C
C--------------------------------------------------------------------------
C
      SUBROUTINE SOLV(OMC)
C
C.....SUBROUTINE TO SOLVE FOR MODE SHAPE COEFFICIENTS FOR GIVEN OMC
C
C***************************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***************************************************************************
C
      DOUBLE PRECISION AD,BD,ARG,OMC,COEF,OMNAT,OMPRD
C
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1          ALP(401),S(401),NSEG
      COMMON/C2/A(401),B(401),AMPL(401),PHAS(401),RAMP(401)
      COMMON/C4/AD(401),BD(401)
      COMMON/C5/STIF(401),STWT(401),OMNAT(401)
      COMMON/DEVICE/IIN,IOUT,IADF
      COMMON/MXAMP/SEGSIR(401),SEGSIZ(401),MXSEG,BSIZE,BPSIZE,BSIZER,
     1              BPSIZR
C
C***************************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     ABS(X)    = DABS(X)
C     SQRT(X)   = DSQRT(X)
C
C***************************************************************************
C
      OMPRD = 1.D0
      DO 50 I = 1,NSEG
      IF(OMNAT(I).GT.1.0D-6)OMPRD = OMPRD*(OMC-OMNAT(I))
   50 CONTINUE
C
      AD(1)  = DSIGN(1.D0,OMPRD)
      A(1)   = AD(1)
      BD(1)  = 0.D0
      B(1)   = BD(1)
      BSIZE  = 0.D0
```

```
      BPSIZE = 0.D0
      TC(NSEG+1)  = 1.D0
      ALP(NSEG+1) = 1.D0
C
      DO 100 I = 1,NSEG
      ARG     = ALP(I)*OMC*CL(I)
      BD(I+1) = AD(I)*DSIN(ARG) +BD(I)*DCOS(ARG)
      B(I+1)  = BD(I+1)
      COEF    = STIF(I)/OMC/(1.D0-(OMNAT(I)/OMC)**2)-AW(I)*OMC/32.2D0
      AD(I+1) = (ALP(I)*(AD(I)*DCOS(ARG)-BD(I)*DSIN(ARG))*TC(I)
     1          +COEF*BD(I +1))/ALP(I+1)/TC(I+1)
      A(I+1)  = AD(I+1)
C
      CALL AMPH(OMC,I)
C
  100 CONTINUE
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE TCDRG
C
C.....SUBROUTINE TO AVERAGE DRAG COEFFICIENT OVER WHOLE CABLE
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1          ALP(401),S(401),NSEG
      COMMON/C3/CDC(401),CDA(401),DEFF(401),PRA(401),CD(401),CDAR(401)
      COMMON/C8/CPRA,PRASUM,CDT,CDTOT,CDWT,CDCAV,CDAAV
C
      PR = 0.D0
      DO 10 I = 1,NSEG
      PR = PR  + CL(I)*CD(I)*(D(I)/12.D0)
   10 CONTINUE
      CDT = PR/CPRA
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE TITLRD(IEOF,ND,IDAT)
C
C.....SUBROUTINE TO READ/WRITE TITLE AND PRINT GENERAL PROGRAM INFORMATION
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      INTEGER TITLE
C
      COMMON/DEVICE/IIN,IOUT,IADF
      COMMON/PLTINF/IPLTCD,PLEN,IPSPEC,IPSTRT,IPSTOP,TITLE(8)
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     NPREC = 2
C     GOTO 10
```

```
C
C****************************************************************************
C
      NPREC = 1
C
C.....READ TITLE INFORMATION
C
   10 READ(IIN,1001)(TITLE(J),J=1,8)
      IF(EOF(IIN))999,11
 1001 FORMAT(8A10)
   11 READ(IIN,1002)IDAT
 1002 FORMAT(I5)
      IF(IDAT.EQ.1)GOTO 9999
C
      CALL DATE(IDAY)
      CALL TIME(ITIM)
C
C.....WRITE TITLE INFORMATION
C
      WRITE(IOUT,2001)(TITLE(K),K=1,8),IDAY,ITIM
 2001 FORMAT(1H1,8A10//" DATE - ",A10,"  TIME - ",A10)
C
C.....WRITE PROGRAM PRECISION
C
      IF(NPREC.EQ.1)WRITE(IOUT,1997)
      IF(NPREC.EQ.2)WRITE(IOUT,1998)
 1997 FORMAT(/" +++++++++PROGRAM RUNNING IN SINGLE PRECISION+++++++++"/)
 1998 FORMAT(/" +++++++++PROGRAM RUNNING IN DOUBLE PRECISION+++++++++"/)
      WRITE(IOUT,1999)
 1999 FORMAT(1X,128(1H-)//)
C
C.....WRITE GENERAL PROGRAM INFORMATION
C
      WRITE(IOUT,2010)
 2010 FORMAT(/,44X,"N O T E S   O N   O U T P U T   D A T A")
      WRITE(IOUT,2011)
 2011 FORMAT(//" 1. ALL WEIGHTS ARE TOTAL EFFECTIVE WEIGHTS AND INCLUDE
     1EFFECTS OF ADDED WATER MASS.")
      WRITE(IOUT,2012)
 2012 FORMAT(/" 2. MODE SEARCH VELOCITY LIMITS CALCULATED FROM STROUHAL"
     11H',"S RELATIONSHIP USE MIN. DIAMETER FOR LOWER LIMIT"/"    AND MA
     2X. DIAMETER FOR UPPER LIMIT AND INCREMENT.")
      WRITE(IOUT,2013)
 2013 FORMAT(/" 3. DRAG IS NOT CALCULATED ON SPRUNG MASSES.")
      WRITE(IOUT,2014)
 2014 FORMAT(/" 4. TABULATED RESPONSE AMPLITUDES ARE ONE HALF OF THE PEA
     1K TO PEAK RESPONSE.")
      WRITE(IOUT,2015)
 2015 FORMAT(/" 5. IN THE OUTPUT DATA, AN ASTERISK (*) BESIDE A SEGMENT
     1NO. INDICATES THAT THIS SEGMENT IS ACTIVE"/"    FOR THE PARTICULAR
     2 MODE AND FLOW VELOCITY, I.E. IT IS BEING EXCITED BY VORTEX SHEDDI
     3NG.")
C
C.....WRITE HEADINGS FOR INPUT DATA
C
      WRITE(IOUT,2020)ND
 2020 FORMAT(/1X,128(1H-)/1X,"INPUT DATA SET NO.",I3//" |",2X,"SEGMENT
     1 DEFINITION",4X,"|",9X,"CABLE   SEGMENT   DATA",8X,"|",9X,
     2"ATTACHED   WEIGHT   DATA",9X,"|",1X,"SPRUNG WT DATA",1X,"|"/)
      WRITE(IOUT,2021)
 2021 FORMAT(/" SEG",5X,"LENGTH",3X,"ARC LENGTH",3X,"DIAM",6X,"DRAG",3X,
     1"WT/LENGTH",3X,"TENSION",4X,"ATTACHED",3X,"DRAG",3X,"PROJ AREA",
     2 2X,"EFFECT DIA",2X,"ATT SPR",2X,"SPRUNG"/
     3 2X,"NO",6X,"(FT)",7X,"(FT)",6X,"(IN)",6X,"COEF",4X,"(LB/FT)",5X,
     4"(LB)",6X,"WT  (LB)",3X,"COEF",4X,"(FT**2)",6X,"(IN)",5X,"(LB/FT)"
     5 ,2X,"WT (LB)"/)
C
      GOTO 9999
C
  999 IEOF=1
```

```
 9999 CONTINUE
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE TWDRG(NSEG)
C
C.....SUBROUTINE TO CALCULATE MODIFIED DRAG COEFFICIENT ON ATTACHED MASSES
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      COMMON/C2/A(401),B(401),AMPL(401),PHAS(401),RAMP(401)
      COMMON/C3/CDC(401),CDA(401),DEFF(401),PRA(401),CD(401),CDAR(401)
      COMMON/C8/CPRA,PRASUM,CDT,CDTOT,CDWT,CDCAV,CDAAV
C
      CDWT    = 0.D0
      CDAW    = 0.D0
      DO 10 I = 1,NSEG
      CDAR(I) = (1.D0+1.82024D0*(A(I+1)/DEFF(I))**0.65D0)*CDA(I)
      CDAW    = CDAW + CDAR(I)*PRA(I)
   10 CONTINUE
      IF(PRASUM.EQ.0)GOTO 20
      CDWT    = CDAW/PRASUM
   20 IF(CDCAV.LT.1.0D-6 .AND. CDAAV.LT.1.0D-6)GOTO 30
      CDTOT   = (((CDT*CPRA+CDAW)/(CDCAV*CPRA+CDAAV*PRASUM))-1.D0)*100.D0
      RETURN
C
   30 CDTOT   = 0.D0
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE UNIT (A1,B1,C,UNITS,D1,D2)
C
C.....SUBROUTINE TO CONVERT FROM INPUT UNITS TO RAD/SEC FOR SEARCHING
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      INTEGER UNITS
C
      COMMON/CONST/PI,STRHN
      DIMENSION OMEGA(3),DIAM(2)
C
      RAD(X) = X*2.D0*PI
      OMEGA(1) = A1
      OMEGA(2) = B1
      OMEGA(3) = C
      DIAM(1) = D1
      DIAM(2) = D2
      GO TO (10,20,30,40,50),UNITS
C
C.....UNITS ARE RAD/SEC
C
   10 RETURN
C
C.....UNITS ARE HERTZ
C
```

```
   20 DO 25 J=1,3
   25 OMEGA(J) = RAD(OMEGA(J))
      GO TO 100
C
C.....UNITS ARE FT/SEC
C
   30 DO 35 I=1,2
   35 OMEGA(I) = OMEGA(I)*2.D0*PI*STRHN/(DIAM(I)/12.D0)
      OMEGA(3) = OMEGA(3)*2.D0*PI*STRHN/(DIAM(1)/12.D0)
      GO TO 100
C
C.....UNITS ARE CM/SEC
C
   40 DO 45 I=1,2
   45 OMEGA(I) = OMEGA(I)/30.48D0*2.D0*PI*STRHN/(DIAM(I)/12.D0)
      OMEGA(3) = OMEGA(3)/30.48D0*2.D0*PI*STRHN/(DIAM(1)/12.D0)
      GO TO 100
C
C.....UNITS ARE KNOTS
C
   50 DO 55 I=1,2
   55 OMEGA(I) = OMEGA(I)/0.5921D0*2.D0*PI*STRHN/(DIAM(I)/12.D0)
      OMEGA(3) = OMEGA(3)/0.5921D0*2.D0*PI*STRHN/(DIAM(1)/12.D0)
  100 A1 = OMEGA(1)
      B1 = OMEGA(2)
      C  = OMEGA(3)
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE WRITE(OMC,MNO,STRVEL,BX,NMASS)
C
C.....SUBROUTINE TO WRITE CALCULATED MODE SHAPE DATA
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      DOUBLE PRECISION BX,OMNAT
C
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1          ALP(401),S(401),NSEG
      COMMON/C2/A(401),B(401),AMPL(401),PHAS(401),RAMP(401)
      COMMON/C3/CDC(401),CDA(401),DEFF(401),PRA(401),CD(401),CDAR(401)
      COMMON/C5/STIF(401),STWT(401),OMNAT(401)
      COMMON/C7/CP(401),DS,ZETA,ZETAE,RHOW,RMU
      COMMON/C8/CPRA,PRASUM,CDT,CDTOT,CDWT,CDCAV,CDAAV
      COMMON/CONST/PI,STRHN
      COMMON/DEVICE/IIN,IOUT,IADF
      COMMON/DIAM/DU(401),NOD
      COMMON/MODE/MXMDS,OMSTRT,OMSTOP,DELOM,ACC,ITCT,IAPROX,IBCODE
      COMMON/MXAMP/SEGSIR(401),SEGSIZ(401),MXSEG,BSIZE,BPSIZE,BSIZER,
     1          BPSIZR
      COMMON/OUTLOC/SPLOC(401),IOUTCD,NSPEC
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     ABS(X)     = DABS(X)
C     COS(X)     = DCOS(X)
C     SQRT(X)    = DSQRT(X)
C
C***********************************************************************
C
      CALL CONVRT(OMC,DS,HOMC,VELFT,VELCM,STRVEL)
```

```
C
C.....WRITE OUT CONVERGENCE FAILURE WARNING(S), IF APPROPRIATE.
C
      IF(IAPROX.EQ.0)GO TO 10
      IF(IAPROX.EQ.1 .OR. IAPROX.EQ.3)WRITE(IOUT,2001)
      IF(IAPROX.GE.2)WRITE(IOUT,2002)
      WRITE(6,2003)
 2001 FORMAT(" ***** INADEQUATE CONVERGENCE FOR THIS MODE *****"/)
 2002 FORMAT(" ***** EXCESS ITERATIONS IN DAMPING CALCULATION *****"/)
 2003 FORMAT(" ***** APPROXIMATE RESULTS LISTED...CAUTION!!! *****"/
     1       " *****      REFER TO USER MANUAL, CHAPTER 6      *****"//)
      IAPROX = 0
C
   10 WRITE(IOUT,2004)MNO,OMC,VELFT,HOMC,VELCM,DS,STRVEL
 2004 FORMAT (/" MODE NO ",I4,//" FREQUENCY = ",1PE10.3," RAD/SEC",
     1 3X," AVERAGE STROUHAL VELOCITY ",1PE10.3," FT/SEC"/11X,"= ",
     2 1PE10.3," HERTZ",10X,"BASED ON DIAMETER",5X,1PE10.3,
     3 " CM/SEC"/39X,"OF ",1PE10.3," IN.",5X,1PE10.3," KNOTS")
      WRITE(IOUT,2005)ZETAE,RMU
 2005 FORMAT(/" EFFECTIVE FLUID/STRUCTURE DAMPING = ",1PE10.3,2X,
     1 " EFFECTIVE MASS PARAMETER = ",1PE10.3)
      WRITE(IOUT,2006)BSIZER,MXSEG
 2006 FORMAT(/" MAX DISPLACEMENT = ",1PE10.3,"  OCCURING IN SEGMENT ",
     1"NUMBER ",I3)
      WRITE(IOUT,2007)BX
 2007 FORMAT(/" ACCURACY ATTAINED (ERROR IN END BOUNDARY CONDITION AS PE
     1RCENT OF MAX. DISPLT....SEE USER MANUAL) = ",0PF9.3," %")
C
      IF(IOUTCD.GE.3) GO TO 120
      WRITE(IOUT,2008)
 2008 FORMAT(/9X,"CABLE RESPONSE",14X,"MASS RESPONSE")
      IF(MOD.GT.1) GO TO 20
      WRITE(IOUT,2009)
 2009 FORMAT(/" SEGMENT",3X," MAX SEG ",2X,"DRAG COEF",
     1 3X,"MASS RESP",2X,"DRAG COEF",3X,"SPRING MASS"/
     2 3X,"NO",6X,"AMPL (IN)",14X,"AMPL (IN)",2X," ATT WTS.",
     3 2X,"NAT FREQ (HZ)")
      GO TO 30
   20 WRITE(IOUT,2010)
 2010 FORMAT (83X," SEGMENT"/" SEGMENT",3X," MAX SEG ",2X,"DRAG COEF",
     1 3X,"MASS RESP",2X,"DRAG COEF",3X,"SPRING MASS",
     2 10X," STROUHAL VELOCITY"/
     3 3X,"NO",6X,"AMPL (IN)",14X,"AMPL (IN)",2X," ATT WTS.",
     4 2X,"NAT FREQ (HZ)",5X,"FT/SEC",4X,"CM/SEC",5X,"KNOTS"/)
   30 NSEG1 = NSEG - 1
      IF(IBCODE.EQ.1)NSEG1 = NSEG
      IF(IBCODE.EQ.0 .AND. NSEG.EQ.1)GOTO 46
      DO 100 I = 1,NSEG1
C
      OMNATF = OMNAT(I)/2.D0/PI
      IF(MOD.NE.1)GOTO 40
      IF(CP(I).LT.0.5D0)GOTO 35
      WRITE(IOUT,2011)I,SEGSIR(I),CD(I),A(I +1),CDAR(I),OMNATF
 2011 FORMAT (2X,I3," *",3X,1PE10.3,0PF9.3,4X,1PE10.3,0PF9.3,7X,0PF7.3)
      GOTO 100
   35 WRITE(IOUT,2111)I,SEGSIR(I),CD(I),A(I +1),CDAR(I),OMNATF
 2111 FORMAT (2X,I3,5X,1PE10.3,0PF9.3,4X,1PE10.3,0PF9.3,7X,0PF7.3)
      GOTO 100
C
   40 CALL CONVRT(OMC,D(I),HERTZ,VELFT,VELCM,VELKTS)
C
      IF(CP(I).LT.0.5D0)GOTO 45
      WRITE(IOUT,2012)I,SEGSIR(I),CD(I),A(I +1),CDAR(I),OMNATF,
     1 VELFT,VELCM,VELKTS
 2012 FORMAT (2X,I3," *",3X,1PE10.3,0PF9.3,4X,1PE10.3,0PF9.3,
     1       7X,0PF7.3,6X,3(1PE10.3))
      GOTO 100
   45 WRITE(IOUT,2112)I,SEGSIR(I),CD(I),A(I +1),CDAR(I),OMNATF,
     1 VELFT,VELCM,VELKTS
 2112 FORMAT (2X,I3,5X,1PE10.3,0PF9.3,4X,1PE10.3,0PF9.3,
```

```
     1         7X,0PF7.3,6X,3(1PE10.3))
C
  100 CONTINUE
C
      IF(IBCODE.EQ.1)GOTO 120
   46 IF(NOD.NE.1)GO TO 110
C
      IF(CP(NSEG).LT.0.5D0)GOTO 50
      WRITE(IOUT,2013)NSEG,SEGSIR(NSEG),CD(NSEG),A(NSEG+1)
 2013 FORMAT (2X,I3," *",3X,1PE10.3,0PF9.3,4X,1PE10.3,
     1         3X,"BOUNDARY",4X,"BOUNDARY")
      GOTO 120
   50 WRITE(IOUT,2113)NSEG,SEGSIR(NSEG),CD(NSEG),A(NSEG+1)
 2113 FORMAT (2X,I3,5X,1PE10.3,0PF9.3,4X,1PE10.3,
     1         3X,"BOUNDARY",4X,"BOUNDARY")
      GOTO 120
C
  110 CALL CONVRT(OMC,D(NSEG),HERTZ,VELFT,VELCM,VELKTS)
C
      IF(CP(NSEG).LT.0.5D0)GOTO 115
      WRITE(IOUT,2014)NSEG,SEGSIR(NSEG),CD(NSEG),A(NSEG +1),
     1               VELFT,VELCM,VELKTS
 2014 FORMAT (2X,I3," *",3X,1PE10.3,0PF9.3,4X,1PE10.3,3X,
     1         "BOUNDARY",4X,"BOUNDARY",6X,3(1PE10.3))
      GOTO 120
  115 WRITE(IOUT,2114)NSEG,SEGSIR(NSEG),CD(NSEG),A(NSEG +1),
     1               VELFT,VELCM,VELKTS
 2114 FORMAT (2X,I3,5X,1PE10.3,0PF9.3,4X,1PE10.3,3X,
     1         "BOUNDARY",4X,"BOUNDARY",6X,3(1PE10.3))
C
  120 WRITE(IOUT,2015)CDT,CPRA
 2015 FORMAT(/" AVERAGE CABLE DRAG COEF = ",0PF9.3," BASED ON PROJECTED
     1CABLE AREA OF ",1PE10.3," (FT**2)")
      WRITE(IOUT,2016)CDWT,NMASS,PRASUM
 2016 FORMAT(/" AVERAGE MASS DRAG COEF  = ",0PF9.3," OVER ",I3,
     1" MASSES AND PROJECTED AREA OF",1PE10.3)
      WRITE(IOUT,2017)CDTOT
 2017 FORMAT(/" PERCENTAGE INCREASE IN AVERAGE DRAG COEF., INCLUDING ATT
     1ACHED MASSES (SEE USER MANUAL) =",0PF9.3,"%")
C
      IF(IOUTCD.EQ.2 .OR. IOUTCD.EQ.4)GOTO 300
      WRITE(IOUT,2018)NSPEC
 2018 FORMAT(//" RESPONSE AMPLITUDES AT",I3," SPECIFIED LOCATIONS.",
     1" DISTANCES FROM LEFT END OF CABLE ASSEMBLY")
      WRITE(IOUT,2019)
 2019 FORMAT(/" SPECIFIED",3X,"  IN   ",3X,"  RESP.  ",3X,"SEG RESP",5X,
     1"SEGMENT"/" LOCN (FT)",3X,"SEGMENT",3X,"AMPL (IN)",3X,"AMPL (IN)",
     2 3X,"DRAG COEF")
      J = 1
      DO 200 I = 1,NSPEC
      SBEG = 0.D0
  210 IF(J.GT.1)SBEG = S(J-1)
      SEND = S(J)
      IF(SPLOC(I).GT.SBEG .AND. SPLOC(I).LT.SEND)GOTO 220
      GOTO 230
  220 ISEG = J
      X      = SPLOC(I)-SBEG
      AMODE = ABS(RAMP(ISEG)*COS(X*OMC*ALP(ISEG)-PHAS(ISEG)))
      IF(CP(ISEG).LT.0.5D0)GOTO 225
      WRITE(IOUT,2020)SPLOC(I),ISEG,AMODE,SEGSIR(ISEG),CD(ISEG)
 2020 FORMAT(F9.2,5X,I3," *",1X,2(2X,1PE10.3),4X,0PF7.3)
      GOTO 200
  225 WRITE(IOUT,2120)SPLOC(I),ISEG,AMODE,SEGSIR(ISEG),CD(ISEG)
 2120 FORMAT(F9.2,5X,I3,3X,2(2X,1PE10.3),4X,0PF7.3)
      GOTO 200
  230 J = J+1
      GOTO 210
  200 CONTINUE
C
  300 WRITE(IOUT,2021)
```

```
 2021 FORMAT(//1H ,8("** --------- **"),"** -----")
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE WRTAX1(NCOUNT)
C
C.....SUBROUTINE TO WRITE GENERAL INFO AND SEGMENT DATA
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      INTEGER TITLE
C
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1          ALP(401),S(401),NSEG
      COMMON/DEVICE/IIN,IOUT,IADF
      COMMON/PLTINF/IPLTCD,PLEN,IPSPEC,IPSTRT,IPSTOP,TITLE(8)
C
      WRITE(IADF,3001)(TITLE(J),J=1,8)
 3001 FORMAT(8A10/4X,1H1)
      WRITE(IADF,3002)NSEG,IPLTCD,PLEN,NCOUNT
 3002 FORMAT(" NSEG",5X,"NPLOT",5X,"PLEN",5X,"NCOUNT"/I5,5X,I5,
     1       4X,F6.0,6X,I3)
      WRITE(IADF,3003)
 3003 FORMAT("    I",8X,"CL(I)",11X,"S(I)",11X,"D(I)",10X,"ALP(I)",
     1       9X,"AW(I)")
      DO 10 I = 1,NSEG
      WRITE(IADF,3004)I,CL(I),S(I),D(I),ALP(I),AW(I)
 3004 FORMAT(I5,5(5X,1PE10.3))
   10 CONTINUE
C
      RETURN
      END
C
C-----------------------------------------------------------------------
C
      SUBROUTINE WRTAX2(OMC,MNO)
C
C.....SUBROUTINE TO WRITE MODAL DATA
C
C***********************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C***********************************************************************
C
      INTEGER TITLE
C
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1          ALP(401),S(401),NSEG
      COMMON/C2/A(401),B(401),AMPL(401),PHAS(401),RAMP(401)
      COMMON/CONST/PI,STRHN
      COMMON/DEVICE/IIN,IOUT,IADF
      COMMON/MODE/MXMDS,OMSTRT,OMSTOP,DELOM,ACC,ITCT,IAPROX,IBCODE
      COMMON/PLTINF/IPLTCD,PLEN,IPSPEC,IPSTRT,IPSTOP,TITLE(8)
C
      WRITE(IADF,3001)
 3001 FORMAT(1H )
      WRITE(IADF,3002)MNO,OMC,ITCT
 3002 FORMAT(" MODE NO =",I5,5X,"FREQUENCY =",4X,1PE10.3,
     1       "NO. ITERATIONS = ",I3)
      WRITE(IADF,3003)IPSTRT,IPSTOP
```

```
 3003 FORMAT("  IPSTRT",9X,"IPSTOP"/2(I5,10X))
      WRITE(IADF,3004)
 3004 FORMAT(3X,1HI,8X,"PHAS(I)",8X,"AMPL(I)",9X,"A(I)",11X,"B(I)",
     1       9X,"NZX(I)",5X,"WAVL(I)")
      DO 100 I = 1,NSEG
      WAVL = 2.D0 * PI/ALP(I)/OMC
      WRITE(IADF,3005)I,PHAS(I),AMPL(I),A(I),B(I),NZX(I),WAVL
 3005 FORMAT(I5,5X,4(1PE10.3,5X),I5,5X,1PE10.3)
  100 CONTINUE
      IF(IBCODE.EQ.1)GOTO 110
      WRITE(IADF,3006)B(NSEG+1)
 3006 FORMAT(40X,1PE10.3)
      GOTO 120
  110 WRITE(IADF,3006)A(NSEG+1)
  120 CONTINUE
C
      RETURN
      END
C
C--------------------------------------------------------------------------
C
      SUBROUTINE WRTAX3(K,NSEG)
C
C.....SUBROUTINE TO WRITE RESPONSE DATA TO AUXILLIARY DATA FILE
C
C**************************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C**************************************************************************
C
      COMMON/C2/A(401),B(401),AMPL(401),PHAS(401),RAMP(401)
      COMMON/C7/CP(401),DS,ZETA,ZETAE,RHOW,RMU
      COMMON/DEVICE/IIN,IOUT,IADF
      COMMON/MXAMP/SEGSIR(401),SEGSIZ(401),MXSEG,BSIZE,BPSIZE,BSIZER,
     1             BPSIZR
C
      WRITE(IADF,3001)K,DS
 3001 FORMAT(I5/" EXCITED DIAMETER = ",1PE10.3)
      WRITE(IADF,3002)
 3002 FORMAT(3X,1HI,7X,"RAMP(I)",8X,"SEGSIR(I)",8X,"A(I+1)")
      DO 100 I = 1,NSEG
      WRITE(IADF,3003)I,RAMP(I),SEGSIR(I),A(I+1)
 3003 FORMAT(I5,3(5X,1PE10.3))
  100 CONTINUE
C
      RETURN
      END
C
C--------------------------------------------------------------------------
C
      SUBROUTINE ZEROX(OMC,MNO,BX)
C
C.....SUBROUTINE TO COUNT ZERO CROSSINGS OF CURRENT MODE
C
C**************************************************************************
C.....REMOVE COMMENT CARDS IN THIS BLOCK FOR DOUBLE PRECISION OPERATION
C
C     IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C**************************************************************************
C
      DOUBLE PRECISION AD,BD,OMC,PR,PID,PHASD,PH,ARG,BX
C
      COMMON/C1/CL(401),D(401),WC(401),TC(401),AW(401),NZX(401),
     1          ALP(401),S(401),NSEG
      COMMON/C4/AD(401),BD(401)
      COMMON/MODE/MXMDS,OMSTRT,OMSTOP,DELOM,ACC,ITCT,IAPROX,IBCODE
C
```

```
      PID     = DABS(DATAN2(0.D0,-1.D0))
      IF(NSEG.GT.1)GOTO 5
      NZX(1) = IDINT(ALP(1)*OMC*CL(1)/PID-0.01D0)
      MNO    = NZX(1)
      GOTO 45
    5 NZX(1) = IDINT(ALP(1)*OMC*CL(1)/PID)
      MNO    = NZX(1)
      NSEG1  = NSEG-1
      IF(NSEG.EQ.2) GO TO 40
      DO 30 I=2,NSEG1
      PH     = ALP(I)*OMC*CL(I)/PID/2.D0
      IF (BD(I)*BD(I +1) .GT. 0.D0) GO TO 10
      NZX(I) = 2*IDINT(PH)  +1
      GO TO 20
   10 NZX(I) = 2*IDINT(PH +0.5D0)
   20 MNO    = MNO  + NZX(I)
   30 CONTINUE
   40 PHASD  = DATAN2(AD(NSEG),BD(NSEG))
      NL     = (1 +IDINT(DABS(PHASD)*2.D0/PID))/2
      IF (PHASD .LT. 0.D0) NL = -1*NL
      ARG    = ALP(NSEG)*OMC*CL(NSEG)
      PR     = ARG-PHASD +1.5D0
      NR     = (1 +IDINT(DABS(PR)*2.D0/PID))/2
      IF (PR .LT. 0.D0) NR = -1*NR
      NZX(NSEG) = NL +NR
      MNO    = MNO +NZX(NSEG)
      IF(IBCODE.EQ.0) GOTO 50
   45 MNO    = MNO+1
      RETURN
C
   50 CONTINUE
C
C.....CORRECTION TO MODE NO. FOR NON-CONVERGENCE IN SEARCH ALGORITHM
C
C     IF(DABS(BX/100.D0).LE.ACC)RETURN
C     DYDX   = AD(NSEG)*DCOS(ARG)-BD(NSEG)*DSIN(ARG)
C     IF(BD(NSEG+1).GE.0.D0  .AND.DYDX.LT.0.D0)RETURN
C     IF(BD(NSEG+1).LE.0.D0  .AND.DYDX.GT.0.D0)RETURN
C     MNO    = MNO-1
C
      RETURN
      END
/*EOR
```

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