REVIEW AND COMMENTS ON:
PLACID FLOATING PRODUCTION SYSTEM
GREEN CANYON, OFFSHORE LOUISIANA
83.5-IN. FREESTANDING RISER

For:

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1. INTRODUCTION

The Placid Oil Company is proceeding with an extensive subsea development program in the deep waters of the Gulf of Mexico off Louisiana (Littleton, 1986). The project will be located in 1540-ft waters of the Green Canyon exploration sector. This landmark production system will consist of a subsea template; a freestanding riser; a moored, semisubmersible production platform; and compliant, catenary riser or pipe bundles connecting the freestanding riser to the platform. An artist's drawing of the production system is shown in Fig. 1.

The purpose of this review is to assess the freestanding riser's vulnerability to vortex-induced vibrations. These so-called strumming vibrations are caused by the periodic shedding of vortices as a current flows over an unstreamlined cylindrical structure such as a riser. Vortex-induced vibrations significantly increase the steady hydrodynamic drag force on a long, slender cylinder. Fatigue also is a consideration when the vibrations occur over a sustained time period.

2. THE FREESTANDING RISER SYSTEM

The riser will be an 83.5-in. diameter freestanding structure extending from the subsea template to a point 150 ft below the water surface; thus the length of the riser will be approximately 1390 ft. The outer cylindrical shell of the riser system will act as a containment for the air cans and syntactic foam which will provide neutral buoyancy for the system. Well flow lines (24), well service lines (24), and liquid and gas export lines (one each) will be contained within the 83.5-in. outer diameter of the overall cylindrical shell.

The uppermost 100 ft of the riser will be surrounded by a 15 ft diameter air can system to provide added buoyancy. The riser has been designed to have sufficient buoyancy to be freestanding, but tension will be applied to the riser top via a tensioning system mounted on the moored platform. The tensioning system is intended to synchronize rig and riser motions and thereby to minimize the bending moments at the riser base connection. A more extensive description of the riser system is given by Littleton (1986).

3. DESIGN CONSIDERATIONS

The several most important factors to be considered in an assessment of the vulnerability of the freestanding riser to be installed in the Placid Oil Company development project are listed below:

3.1 Site Description

3.2 Deterministic vs. Random Analysis

3.3 Hydrodynamic Drag and Fatigue

3.4 Suppression of Vortex-Induced Vibrations.

Each of these factors will be addressed briefly here in the order listed.

3.1 Site Description.

The wave and current conditions at the Green Canyon site are not available in any detail for this analysis. However, based upon previous experience the effects of vertical current shear can be expected to play an important role in a design assessment. The basic features of current shear effects are known, but only limited consideration has been given to the practical consequences (Fischer, Jones and King, 1980; Kim, 1984: Griffin, 1985, 1985a).

The combined effects of waves and currents also may be of importance at the Green Canyon field site under extreme conditions. Present offshore engineering practice recommends that wave- and current-induced velocities be added vectorially to obtain the resultant effect of the combined motions (Hogben et al, 1977).

3.2 Deterministic vs. Random Analysis

Many structural and environmental factors complicate any analysis of a system such as the freestanding riser that will be installed in Placid's Green Canyon development project. These factors include current shear, variable riser configuration and mass properties, and variations in tension and water particle speed and direction. Due to both time and economic constraints, some attempt at a deterministic analysis remains the only viable approach for a preliminary riser system design assessment. More complicated time and/or frequency domain analyses to account for the non-resonant or random nature of the vibrations may be required to fully satisfy the project's economic and operational objectives.

Even when the random vortex-induced strumming vibrations of a long ocean cable are considered, as by Kim et al (1984, 1985) for example, the knowledge gained from related deterministic analyses has provided indispendible guidance.

3.3 Hydrodynamic Drag and Fatigue

Vortex-induced vibrations significantly increase the steady drag force on a riser or other similar member. Increases in drag coefficient of up to 250 percent are common and well documented (Griffin, 1985), even for relatively long riser and cable segments which vibrate in a direction normal to a uniform current (Griffin and Vandiver, 1983). It is true, however, that the drag is dependent directly upon the local vibration amplitude along the structure, so that the increased drag is reduced somewhat when the flow is not spatially uniform and the vibrations are non-resonant or random (Kim, 1984).

Fatigue is an important consideration when the vortex-induced vibrations occur at large amplitudes of displacement over a sustained time period. These unsteady stresses are superimposed directly on the increased drag. Thus the cumulative effects of the steady and unsteady stresses must be considered in any design assessment of a proposed marine riser system in a marine environment such as Green Canyon where currents may be an important factor. A mitigating factor at the present time is that such an assessment is restricted to deterministic methods which tend to be somewhat conservative.

3.4 Suppression of Vortex-Induced Vibrations

Various means for reducing and/or eliminating vortex-induced vibrations have been developed in recent years. Extensive discussions of vibration suppression pertinent to ocean engineering applications have been given by Hafen and Meggitt (1977), Every, King and Griffin (1982), and Gardner and Cole (1982). It generally has been found that mass and damping control is ineffective in water. This is because the product of structural mass and damping can be increased by a factor of fifty with only a factor of two decrease in the amplitude of displacement (strumming) due to vortex shedding (Griffin, 1985). Thus some type of external device fitted about the member is required.

Every et al (1982) and Zdravkovich (1984) generally have classified the most effective external strumming suppression devices for cylindrical members into four categories. These include helical ridges (strakes), shrouds (slats and perforated outer casings), splitter plates, and fairings. Rigid, streamlined foil-shaped fairings have been used effectively to suppress strumming under some circumstances. These devices yield relatively low drag coefficients but they are expensive, difficult to handle, and they can undergo large lateral deflections (kiting) at non-zero angles of attack. A fairing must be able to rotate in order to maintain its orientation in line with the current (Gardner and Cole, 1982). The effectiveness of the various strumming suppression devices also is discussed extensively by Every, King and Weaver (1982).

Virtually all strumming suppression devices except for the foil-shaped fairing tend to produce some increase in hydrodynamic drag even when the member is restrained from vibrating ($C_D = 2.5$ to 2.9 for fringe cable fairings, and $C_D = 1.4$ for a helical strake vortex spoiler). These drag coefficients can be compared to the typical values of $C_D = 2.0$ to 2.5 for sustained vortex-induced vibrations at large displacement amplitudes of ±1.5 diameters. Every et al (1982) observed that the attachment of a helical strake vortex spoiler reduced these cross flow displacement amplitudes to ±0.1 to 0.2 diameters. Vibrations of this magnitude would result in an effective drag coefficient of $C_D = 1.5$-1.7. A drag penalty of some sort is paid in most suppression applications. This must be weighed against the effects of the strumming vibrations themselves.

4. FREESTANDING RISER ANALYSIS

A preliminary analysis can be made of the Placid Oil Company freestanding riser using the approach outlined by Griffin (1985). This analysis will include the effects of current shear, vortex lock-on, and expected amplitudes of displacement due to vortex shedding. Information pertaining to the site conditions and the riser design parameters is summarized in Table 1. This information has been provided by Cameron Offshore Engineering of Houston, Texas, the designers of the riser system (D. Hervey, private communication, 1986). The current conditions given in the table are extreme values. More frequently-occurring currents would be smaller in magnitude, perhaps in the range of 2-3 ft/sec. A more complete analysis will require more extensive knowledge of site environmental conditions, riser material properties and construction details, and operational conditions and constraints.

The simplified system considered in the analysis is shown in Fig. 2. The following assumptions apply:

- Linear current shear profile exists at the site (no extreme wave + current conditions).
- Riser is modelled as a long, slender cylindrical member with low bending stiffness (tension most important).
- Structural mass properties are uniform lengthwise along the riser (neutral buoyancy is assumed).
- The effect of the 15 ft diameter buoyancy module on the riser natural frequencies is neglected as a first approximation since it extends over only 1/14 of the total length of the riser.

- o Subcritical Reynolds number ($Re < 10^5$) design data can be extrapolated to the riser operating range ($Re \sim 10^6$).

These have proven to be reasonable assumptions under most circumstances for problems similar to the present one.

4.1 Current Shear Effects

The importance of current shear along the length of the riser can be assessed by evaluating the "steepness of shear" parameter (Griffin, 1985b)

$$\beta = \frac{D}{\overline{V}_{REF}} \frac{\Delta \overline{V}}{\Delta \overline{z}}$$

where

D = riser diameter, ft;

$\overline{V}$ = local current at depth, ft/sec;

$\overline{z}$ = vertical distance along the riser, ft/sec.

The velocity $\overline{V}_{REF}$ is a reference scale, usually taken at mid-length along the structure (riser). Previous experience (Fischer, Jones and King, 1980) has shown that a value of shear steepness parameter in the range $\beta = 0.01$ to 0.015 and below is sufficient to render current shear unimportant in marine applications. That is to say, vortex-induced vibrations of large amplitude on laboratory or field scales occur even in the presence of shear currents when $\beta = 0.01$ to 0.015 or less.

Upon making use of the site conditions and the Placid riser's dimensions as provided by Cameron Offshore Engineering, the following estimate can be made. Assume the extreme current range given in Table 1, and then

$$\bar{V}_{MAX} = 4.5 \text{ ft/sec}$$
$$\bar{V}_{MIN} = 0.5 \text{ ft/sec}$$
$$\bar{V}_{REF} = 2.5 \text{ ft/sec}$$
$$D = 83.5 \text{ in.}$$
$$L = 1390 \text{ ft;}$$

so that

$$\beta = \frac{D}{\bar{V}_{REF}} \frac{\Delta \bar{V}}{\Delta z} = \frac{D\left(\bar{V}_{MAX} - \bar{V}_{MIN}\right)}{\bar{V}_{REF} \quad L}$$

or

$$\beta = 0.0081.$$

It is reasonable to assume that shear currents will not mitigate the occurrence of vortex-induced oscillations. There will be minimal deviations from the uniform incident current response of the freestanding riser.

3.2 Riser Natural Frequencies, Amplitudes of Displacement and Drag

The natural frequencies of the riser can be estimated by assuming that it is a pinned-pinned beam with small stiffness. As a first approximation the effect of the 15 ft diameter buoyancy module is neglected since it extends over only 1/14 of the riser's length. Also, neutral buoyancy is assumed as an operational condition. Then the natural frequencies of the first n natural modes are given by

$$f_n = \frac{n}{2L} \sqrt{\frac{Tg_c}{m_v}} \qquad n = 1,2,3...$$

Here T = riser tension, lb

m_v = virtual mass per unit length, $m_s + m_a$, lb_m/ft

m_s = structural mass, lb_m/ft

m_a = fluid added mass, lb_m/ft

g_c = proportionality constant, 32.2 $lb_m\ ft/lb_f\ sec^2$.

If the added mass is equal to the displaced mass of water for the riser, then

$$m_v = m_s + m_a = 2m_a = 2\ \rho_w(\pi/4\ D^2).$$

Using $\rho_w = 64\ lb_m/ft^3$ for seawater and the total tension of $T = 500\ klb_f$,

$$f_n = 0.021n, \qquad n = 1,2,3...$$

Note in Table 1 that 80 percent of the total tension is provided by the air can buoyancy modules and 20 percent by the tensioners at the top of the riser.

Vortex-lock on and resonant vortex-induced vibrations take place in water when the reduced velocity $V_r = \bar{V}/f_n D$ is in the range $V_r = 4$ to 10-11, for a neutrally buoyant cylinder or riser (Every et al, 1982). The first four natural frequencies are plotted in Fig. 3 against the expected range of current speeds which will cause vortex-induced vibration to occur, as given by $\bar{V} = V_r\ (f_n D)$. The dashed lines are the expected range of currents at the site based upon the information supplied by Cameron Offshore Engineering. It is likely that vortex-induced vibrations will occur in the n = 1, 2 and 3 modes, and possibly part of the n = 4 mode as well. If the currents at the site are limited to a more moderate range, say $\bar{V}_{MAX} = 3$ ft/sec and $\bar{V}_{MIN} = 1.5$ ft/sec, then only the n = 2 and n = 3 modes of the riser are cause for concern. For a riser of neutral buoyancy these vibrations are likely to reach magnitudes of ±1.5 diameters in the cross flow direction (Every et al, 1982; Griffin, 1985) and the drag coefficient for the riser is likely to be in the range $C_D = 2.0$ to 2.5.

Vortex-induced vibrations were observed in the first three natural modes of the 1/11-scale riser sectional model during the model tests conducted for Cameron Offshore Engineering (D. Hervey, private communication, 1986).

5. CONCLUSIONS AND RECOMMENDATIONS

This preliminary analysis gives sufficient cause to conclude that vortex-induced vibrations are a design concern for the freestanding riser which will be installed as part of the Placid Oil Company development in the Green Canyon exploration sector of offshore Louisiana.

The following recommendations are made:

- Further investigation of hydrodynamic drag and fatigue effects should be made, based upon the anticipated lifetime of the freestanding riser, its natural frequencies, and the occurrence frequency and duration of currents at the installation site. The cumulative effects of steady and unsteady stresses are required for a complete design assessment of vortex-induced vibration problems such as this.

- Further study of suitable vortex-induced vibration suppression devices should be made since this is the most promising approach to reducing the anticipated vibrations to tolerable levels. A drag penalty is paid in most strumming suppression applications. This must be weighed against the drag induced by the vibrations themselves.

The helical strake vortex spoiler or suppression device is likely to reduce the vortex-induced vibrations sufficiently, based upon past ocean engineering experience (Every et al, 1982), while paying only a minimal drag penalty (Zdravkovich, 1984). However, the long-term durable lifetime is not known for this device in a deep water installation such as the Placid freestanding riser.

6. REFERENCES

M.J. Every, R. King and O.M. Griffin, 1982, "Hydrodynamic Loads on Marine Structures due to Vortex Shedding", ASME Journal of Energy Resources Technology, Vol. 104, 330-336.

M.J. Every, R. King and D.S. Weaver, 1982, "Vortex-Excited Vibrations of Cables and Cylinders and Their Suppression", Ocean Engineering, Vol. 9, 135-158.

F.J. Fischer, W.T. Jones and R. King, 1980, "Current-Induced Oscilltions of Cognac Piles During Installation," in Practical Experiences With Flow-Induced Vibrations, Springer-Verlag:Berlin, 570-5811.

T.N. Gardner and M.W. Cole Jr., 1982, "Deepwater Drilling in High Current Environment", Offshore Technology Conference Paper OTC 4316.

O.M. Griffin, 1985, "Vortex-Induced Vibrations of Marine Cables and Structures", NRL Memorandum Report 5600.

O.M. Griffin 1985a, "The Effects of Current Shear on Vortex Shedding", Symposium on Separated Flow Around Marine Structures, Norwegian Institute of Technology, Trondheim, June 21-25.

O.M. Griffin, 1985b, "Vortex Shedding from Bluff Bodies in a Shear Flow: A Review", ASME Journal of Fluids Engineering, Vol. 107, 298-306.

O.M. Griffin and J.K. Vandiver, November 1983, "Flow Induced Vibrations of Taut Cables with Attached Masses", Naval Civil Engineering Laboratory Report CR 84.004.

B.E. Hafen and D.J. Meggitt, September 1977, "Cable Strumming Suppression", Naval Civil Engineering Laboratory Technical Note N-1499.

N. Hogben, B.H. Miller, J.W. Searle and G. Ward, 1977, "Estimation of fluid loading on offshore structures", Proceedings of the Institution of Civil Engineers, Vol. 63, 515-563.

Y.-H. Kim, October 1984, "Vortex Induced Response and Drag Coefficients of Long Cables in Ocean Currents", Ph.D. Thesis, MIT.

Y.-H. Kim, J.K. Vandiver and R.A. Holler, February 1985, "Vortex Induced Vibration and Drag Coefficients of Long Cables Subjected to Sheared Flows", Proceedings of the Fourth International Offshore Mechanics and Arctic Engineering Symposium, ASME: New York.

J. Littleton, May 1986, "Placid Pioneers Deepwater Subsea Platform", PETROLEUM ENGINEER International, 21-24.

M.M. Zdravkovich, 1984, "Reduction of effectiveness of means for suppressing wind-induced oscillation", Engineering Structures, Vol. 6, 344-349.

Table 1

PLACID FLOATING PRODUCTION SYSTEM
FREESTANDING RISER

SITE CONDITIONS AND DESIGN INFORMATION*

Site Conditions:

Currents 4 to 5 ft/sec (shear with depth)
Water depth 1540 ft

Riser Properties/Parameters:

Diameter, D = 7 ft
Length, L = 1390 ft
Top Tension, T = 500 klb
(100 klb from tensioners, 400 klb from external buoyancy modules)

Model Test Conditions:

Deep basin 1/20 scale model
Shallow basin 1/56-scale model
Vortex shedding tests conducted with a 1/11-scale (based on riser diameter of 7 ft) sectional model, approximately 30 ft long.

*Information provided by Cameron Offshore Engineering, Houston, Texas.

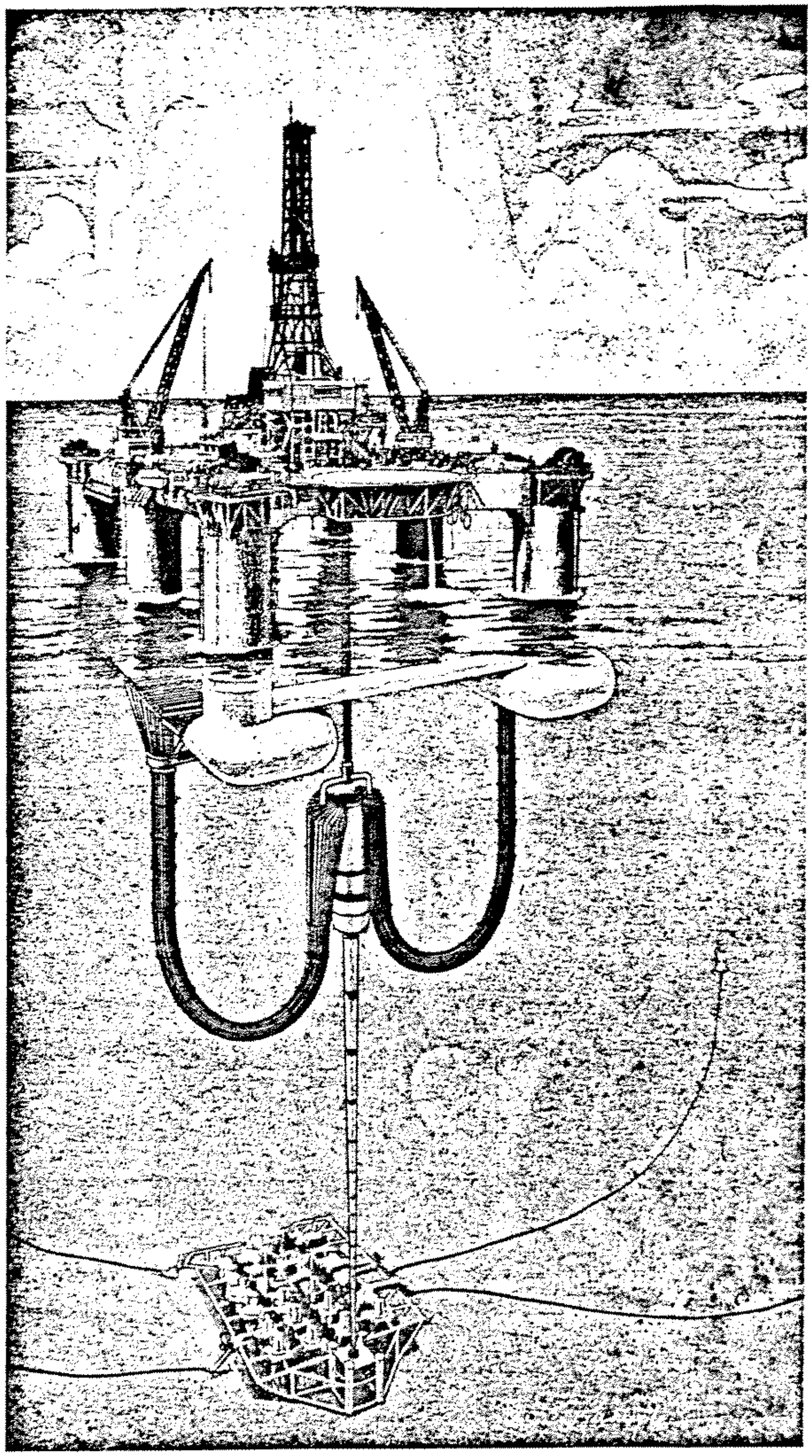


Fig. 1 The Placid Oil Company floating production system.

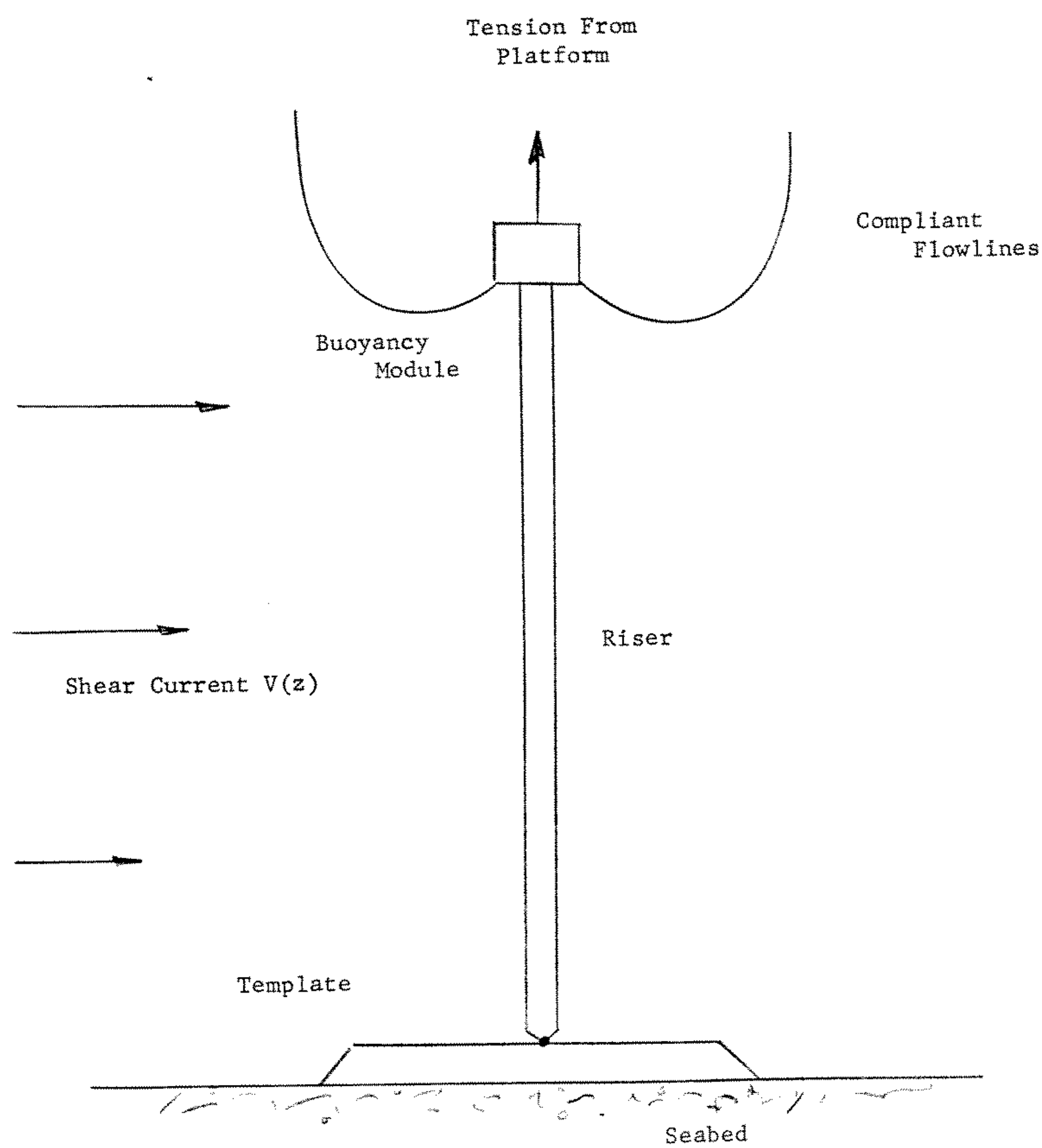
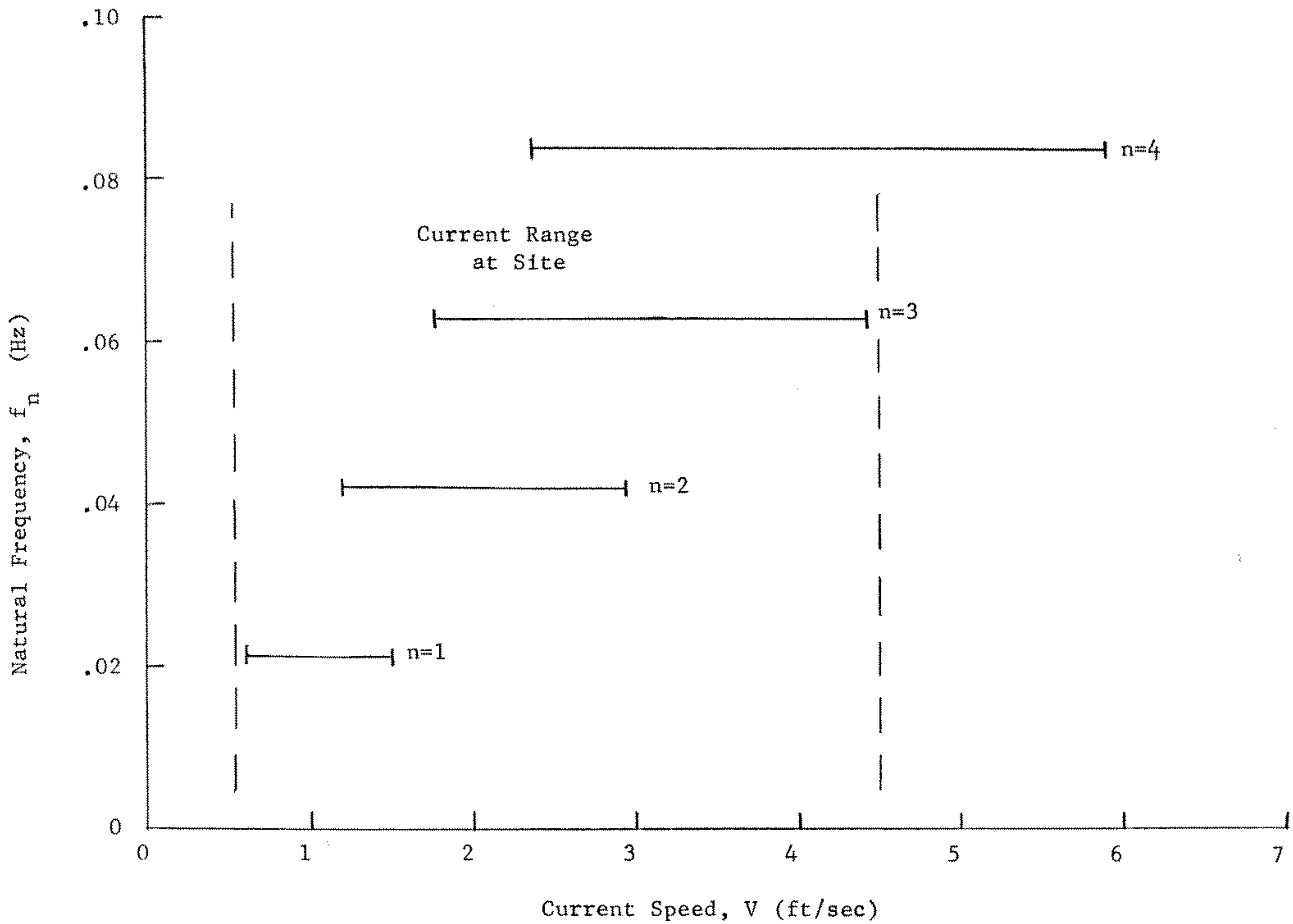


Fig. 2 A sketch of the freestanding riser.


.10
.08
.06
.04
.02
0
Natural Frequency, f_n (Hz)
0
1
2
3
4
5
6
7
Current Speed, V (ft/sec)
Current Range
at Site
n=1
n=2
n=3
n=4