# REVIEW AND COMMENTS ON:
# TEXACO HARVEST PLATFORM DAMAGE ASSESSMENT

For:
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# 1. INTRODUCTION

Underwater damage at several locations on the offshore platform HARVEST operated by Texaco Incorporated were observed during recent underwater inspection/repair activities. The damage has been attributed to fatigue caused by vortex shedding-induced vibrations in air during a trans-Pacific tow and demurrage time in the Santa Barbara channel prior to launching of the platform at sea.

Assessments of the damage and discussions of the repairs undertaken are contained in recent Texaco correspondence to PMB Systems Engineering, the Design Certification Verification Agent (DVA) for the Minerals Management Service (G.E. Mott, 1986a, 1986b). Copies of this correspondence also have been forwarded to the Minerals Management Service in Los Angeles, California and Metairie, Louisiana. Additional information since has been provided during discussions with Texaco's Central Offshore Engineering (January 1987).

The purpose of this review is to assess and comment upon the likelihood of wind-induced vortex shedding as the cause of the damage to the platform members. These so-called strumming vibrations are caused by the periodic shedding of vortices as a relative water current or wind flows over an unstreamlined cylindrical structure such as a marine riser or a jacket structure member. Fatigue also is a consideration when these vibrations of sufficiently large amplitude occur over a sustained time period.

## 2. STRUCTURE OF THE HARVEST PLATFORM

Damage was detected at several locations on the jacket structure of the Harvest platform. The particular locations denoted as Site 7 and Site 8 are considered in the present assessment; other locations are similar in terms of the level and type of damage sustained. The letters and attachments issued by Texaco's Central Offshore Engineering Department (G.E. Mott, 1986a; 1986b) describe the location of the damage, the types of damage sustained (fatigue cracking), and the steps taken to effect repairs.

A sketch of the Site 7 and Site 8 locations is given in Fig. 1. These sites are located approximately 365 ft below the mean water level (MWL) elevation of the platform. The dimensions of the members and the properties required for the present review and assessment are given in Fig. 1 and Table 1.

## 3. DAMAGE ASSESSMENT

The most important factors to be considered in an assessment of the vortex shedding-induced damage during the tow and demurrage of the HARVEST platform are listed below:

3.1 Deterministic vs. Random Analysis
3.2 Hydrodynamic Drag and Fatigue
3.3 Suppression of Vortex-Induced Vibrations.

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

### 3.1 Deterministic vs. Random Analysis

Many structural and environmental factors complicate any analysis of a system such as the HARVEST platform. These factors include variable relative wind speed, direction and duration; member configuration, end conditions and mass properties; and variations in tow speed and conditions. Due to both time and economic constraints, some attempt at a first-order deterministic analysis is the only viable approach for a preliminary damage assessment such as the present one. More complicated time and/or frequency domain analyses to account for the non-resonant or random nature of the vibrations and a finite element analysis of the structure's natural frequencies 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 first-order deterministic analyses has provided indispendible guidance.

## 3.2 Hydrodynamic Drag and Fatigue

Vortex-induced vibrations significantly increase the steady drag force on a riser, tubular or other similar member. Increases in drag coefficient of up to 250 percent for a structure in water 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 known, 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).

Vortex-induced vibrations of a cylindrical member in air are reduced from the comparable levels reached in water by as much as a factor of ten (Griffin, 1984; Simiu and Scanlan, 1986). The reduced level of the vibrations is accompanied by a similar reduction in the drag due to vortex shedding. Typical measurements of the amplitude of displacement normal to an incident flow of air are shown in Fig. 2. The predicted line shown in the figure was calculated using Eq. (5) as given in the paper by Griffin (1984).

Fatigue is an important consideration in both air and water when the vortex-induced vibrations occur at the respective amplitudes of displacement in both media over a sustained time period. These unsteady fatigue stresses are superimposed directly on the increased mean stresses caused by the steady aerodynamic or hydrodynamic drag forces on the member. Thus the cumulative effects of the steady and unsteady stresses must be considered in any assessment of damage as in the present case of the HARVEST platform where relative wind-induced vortex shedding is likely to 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.

## 3.3 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 marine 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, so that some type of external device fitted about the member is required.

Control of the mass and damping of the structure is an effective measure for suppressing vortex-induced vibrations in air (Zdravkovich, 1984). However, external devices such as the helical strake winding often are used in air as shown in Fig. 3. Suppression of the vortex-induced vibrations was not feasible in the case of the HARVEST platform because of the complexity of the jacket structure and, more importantly, because the problems encountered during the trans-Pacific tow and offshore demurrage periods apparently were not anticipated beforehand. An extensive summary of vortex shedding suppression measures was included in a recent report submitted to the Minerals Management Service concerning the proposed Placid Oil Company freestanding riser project proposed for installation in one of the Green Canyon, offshore Louisiana development blocks (Griffin, 1986).

## 4. PLATFORM HARVEST LEG/BRACE ANALYSIS

A preliminary assessment using the approach outlined by Griffin (1986) can be made to determine the likelihood that relative wind-induced vortex shedding was the cause of vibrations which damaged the HARVEST platform during a tow and demurrage of the structure. This analysis includes the effects of vortex lock-on and relative wind magnitude and direction, the expected amplitudes of displacement, the expected levels of the mean aerodynamic forces on the member, and, briefly, fatigue effects. Information pertaining to the platform configuration, and the dimensions and properties of the structural members under consideration is given in Fig. 1 and Table 1. This analysis is limited in scope because of the complexity of the HARVEST platform structure and the relatively limited information which has been made available concerning the platform. A more complete analysis would entail a finite element analysis of the platform members' natural frequencies, and more extensive information relative to the tow operational conditions and duration, and weather and environmental conditions (winds, waves, etc.).

The following assumptions apply to the present analysis:

- The platform legs and braces are modelled as long, slender cylindrical members dominated by stiffness (tension low, structural stiffness most important).

- Structural mass properties are uniform lengthwise along the member and are well-defined.

- The relative wind magnitude and direction are slowly-varying; only the flow component normal to the member is important in exciting the vibrations.

- Subcritical Reynolds number ($Re < 10^5$) design data and approaches can be employed with some confidence. The Reynolds number corresponding to the HARVEST platform demurrage conditions was approximately $Re = 10^7$, but any applicable data are very scarce at such a high value of Re.

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

## 4.2 Natural Frequencies

The natural frequencies of the members labeled A and B in Fig. 1 can be estimated to a reasonable first approximation by considering them to be stiffness-dominated cylindrical beams. This neglects the interdependence of the subelements of the overall structure but no computer code is readily available at this time to do a more extensive analysis. The frequencies of the first n natural modes are given by

$$f_n = \frac{\alpha_n^2}{2\pi L^2}\sqrt{\frac{EIg_c}{m_s}} \, . \quad \alpha_n = \alpha_1, \alpha_2, \ldots \text{etc.}$$

where $E$ = Young's modulus, $lb_f/ft^2$;
$I$ = moment of inertia $ft^4$:
$m_s$ = structural mass. $lb_m/ft$:
$g_c$ = proportionality constant. 32.2 $lb_m$ $ft/lb_f$ $sec^2$.

There are no added mass effects on the in-air natural frequencies. The coefficients $\alpha_n$ are listed in Table 2 for the first five natural modes of a uniform cylindrical member. The natural frequencies can be calculated in a straightforward manner and are listed in Table 3.

This first-order approximation to estimating the natural frequencies has proven to be sufficiently accurate. The first mode natural frequencies of the members in question were found to be in the range $f_n$ = 1.5 to 2 Hz, according to information provided by Texaco Central Offshore Engineering (January 1987).

Vortex lock-on and resonant, crossflow vortex-induced vibrations take place in air when the reduced velocity $V_r = \bar{V}/f_nD$ is in the range $V_r = 4.5$ to $7.5$, for a member of circular cross-section. This is somewhat narrower than the comparable range in water, which is $V_r = 4$ to $11$. The relative wind speeds in the range of vortex resonance for HARVEST members A,B can be estimated from the relation

$$V_{1n}, V_{2n} = 4.5, 7.5\ (f_nD)\ \text{ft/sec},$$

which represents the normal or exciting component of the relative flow. The <u>total</u> relative wind speed range is given by

$$V_1, V_2 = V_{1n}, V_{2n}\ (\cos\theta)^{-1},$$

where in the present case $\theta = 45^0$. The subscripts 1 and 2 respectively denote the lower and upper speed limits of the resonance.

The first five natural frequencies are listed in Table 3 for both pinned and clamped end conditions together with the predicted range of relative wind speeds (normal component only) which correspond to vortex resonance. Only the wind speeds pertinent to the first three modes are given since higher speeds are probably of no practical consequence. The very highest relative speeds would be attained only when the platform was under tow into a strong, steady wind for an extended time period. (It is assumed here that the tow speed during the trans-Pacific passage was 5 to 10 kt.) The total relative wind speeds for the first three modes are plotted in Fig. 4. Assuming that the true natural frequencies of the cylindrical members lie in the range between those approximated by pinned and clamped end conditions, one may expect that vortex-induced vibrations in the first mode are most likely to be encountered in the noted range of relative wind speeds.

According to information provided by Texaco Central Offshore Engineering (January 1987), the winds at the offshore site were in the range of 4 to 7 on the Beaufort scale. This translates to a wind speed range of 15 to 40 kt which is similar to the range plotted in Fig.4. However, these winds were observed over extended time intervals at the HARVEST platform installation site when the platform was barge-mounted and stationary in the water. The observed vortex-induced vibrations also were dependent upon the wind direction relative to the members which experienced damage. This directional effect is a result of the yaw angle dependence of the vibrations. At the larger angles, greater than 30 to 40 degrees from normal incid the vibrations become less regular and are much reduced in .. due to the irregularity and complexity of the vortex shedding. This behavior was in fact observed at the site.

### 4.3 Amplitudes of Displacement

Typical measured and predicted in-air amplitudes of displacement due to vortex shedding for a member of cylindrical cross-section are shown in Fig. 2. The horizontal scale is the so-called "reduced damping" parameter (Griffin, 1985; Every, King and Griffin, 1982)

$$k_s - \frac{2m\delta}{},$$

where

$\delta$ = log decrement of structural damping;

$\rho$ = fluid density (air), $lb_m/ft^3$.

and again m is the structural mass density (per unit length) and D is the cylinder diameter as defined previously.

An estimate can be made of $k_s$ for the platform HARVEST members based on the properties and dimensions in Fig. 1 and Table 1. If it is assumed that the structural log decrement $\delta = 0.05$ to 0.10 for a steel pipe, which is reasonable in practice then $k_s = 50$ to 100. This is a typical range of $\delta$ for a riser or conductor pipe conveying fluids. It is seen readily from Fig. 2 that reduced damping in this range limits the amplitude of displacement (from equilibruim) to $\bar{Y} = \pm 0.01D$ (or ± 0.36-in.) and less.

Among the information provided by Texaco Central Offshore Engineering (January 1987) was the estimated log decrement of the structural damping for the members in question. The log decrement of the hollow steel tubulars is $\delta = 0.01$, which is considerably less than the original assumption given above. Thus the reduced damping $k_s$ is of the order $k_s = 10$ or less, a decrease of an order of magnitude from the original estimate. Reference to Fig. 2 then gives a revised crossflow displacement amplitude of $Y = \pm 0.3D$ or somewhat greater, depending on the actual value of the structural damping. Visual observations of the vibrations of the X-frame sketched in Fig.1 estimated the amplitudes of oscillation to be of the order of ± 1D and to be in the general form of breathing or crossflow oscillations normal to the plane of the X-frame when the relative orientations of the barge-mounted platform and the incident wind were aligned in the appropriate manner. These are precisely the vortex-induced vibrations which are likely to cause the most severe problems.

Thus it appears that sustained large-amplitude vibrations due to wind-induced vortex shedding may have been present and of sufficient duration at the offshore installation site to cause the observed damage to the platform members.

### 4.4 Aerodynamic Forces and Fatigue

The expected amplitudes of displacement are sufficient to cause appreciable amplification of the aerodynamic drag on the cylindrical members. It is at the higher amplitudes of displacement which sometimes are encountered in air (see Fig. 2) and which are common in water that amplifications of the force levels well beyond those of an effectively stationary bluff object are encountered. The drag coefficient on the platform members is likely to be in the range $C_D = 1.3$ to $1.6$ at the expected displacement amplitudes, which is an appreciable amplification from the drag ($C_D = 1.0$ to $1.2$ ) on a cylindrical member that is restrained from oscillating.

The prediction of fatigue life is a complex problem and is not very well understood for structural members such as those under consideration here. The fatigue of a member undergoing bending is very difficult to predict, but it is generally recognized that steel has a stress endurance limit which limits the safe survival time of a member. For an infinite number of bending cycles the endurance limit of stainless steel, for example, is approximately one-half the yield stress.

The damage to the HARVEST platform has been postulated to be stress related fatigue failure (Mott, 1986a; 1986b). This cause of damage has been used to reinforce the vortex shedding postulation. The structural properties and parameters of the members and the in situ wind environment which the HARVEST platform experienced provide further evidence that wind-induced vortex shedding was likely to cause large amplitude vibrations of sufficient magnitude and duration to cause the observed fatigue failures.

## 5. SUMMARY AND CONCLUSIONS

This review and assessment gives reason to believe that the relative wind environment encountered by the HARVEST platform was in the range of conditions (magnitude, direction and duration) under which vortex-induced vibrations are likely to have occurred. The structural properties and parameters (natural frequencies and damping) of the platform members which sustained the damage also are such that the vibrations were of sufficient magnitude, duration and regularity to contribute significantly to the members' failures. The flow-induced force amplifications which accompany the vortex-induced vibrations combine to result in the cumulative effects of steady and unsteady force and stress superposition.

Thus stress related fatigue very likely was the ultimate cause of failure as hypothesized by Texaco's engineering staff. Numerous cases of fatigue failure have been documented for marine risers and tubulars under similar wind and water current operating conditions.

## 6. REFERENCES

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## TABLE 1

## TEXACO HARVEST PLATFORM

## PERTINENT STRUCTURAL DIMENSIONS AND PARAMETERS*

Member A, B** Properties/Parameters:

Length, L = 90 ft

Diameter. D = 36 in.

Wall thickness, d = 0.875 in.

Structural mass. m = 300 $lb_m$/ft

Structural damping
(log decrement), $\delta$ = 0.01

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*Information provided by Texaco Central Offshore Engineering, New Orleans LA.

**See Fig. 1.

# TABLE 2

# PLATFORM HARVEST

# BEAM NATURAL FREQUENCY COEFFICIENTS

| Mode Number, $n$ | Coefficient, $\alpha_n$ | |
|---|---|---|
| | pinned-pinned | clamped-clamped |
| 1 | 3.14 | 4.73 |
| 2 | 6.28 | 7.85 |
| 3 | 9.4 | 11.0 |
| 4 | 12.6 | 14.1 |
| 5 | 15.7 | 17.3 |

## TABLE 3

## HARVEST PLATFORM DAMAGE ASSESSMENT

## PREDICTED NATURAL FREQUENCIES<br>AND<br>RELATIVE WIND SPEEDS

| Mode Number, n | Natural frequency, $f_n$ (Hz) | | Relative wind speed range, $V_{1n}$,$V_{2n}$ (ft/sec, kt)* | |
|---|---|---|---|---|
| | pinned-pinned | clamped-clamped | pinned-pinned | clamped-clamped |
| 1 | 1.10 | 2.53 | 14.8/24.7<br>( 8.8/14.7) | 34.1/56.8<br>(20.2/33.6) |
| 2 | 4.42 | 6.97 | 59.5/99.4<br>(35.2/58.8) | 94.0/156.8<br>55.7/ 92.9) |
| 3 | 9.94 | 13.7 | 134.1/223.5<br>(79.4/132.5) | 184.8/308.1<br>(109.4/182.5) |
| 4 | 17.7 | 22.6 | ----------- | ---------- |
| 5 | 27.6 | 33.7 | ------------ | ---------- |

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*Relative wind component normal to members A,B of Fig. 1.

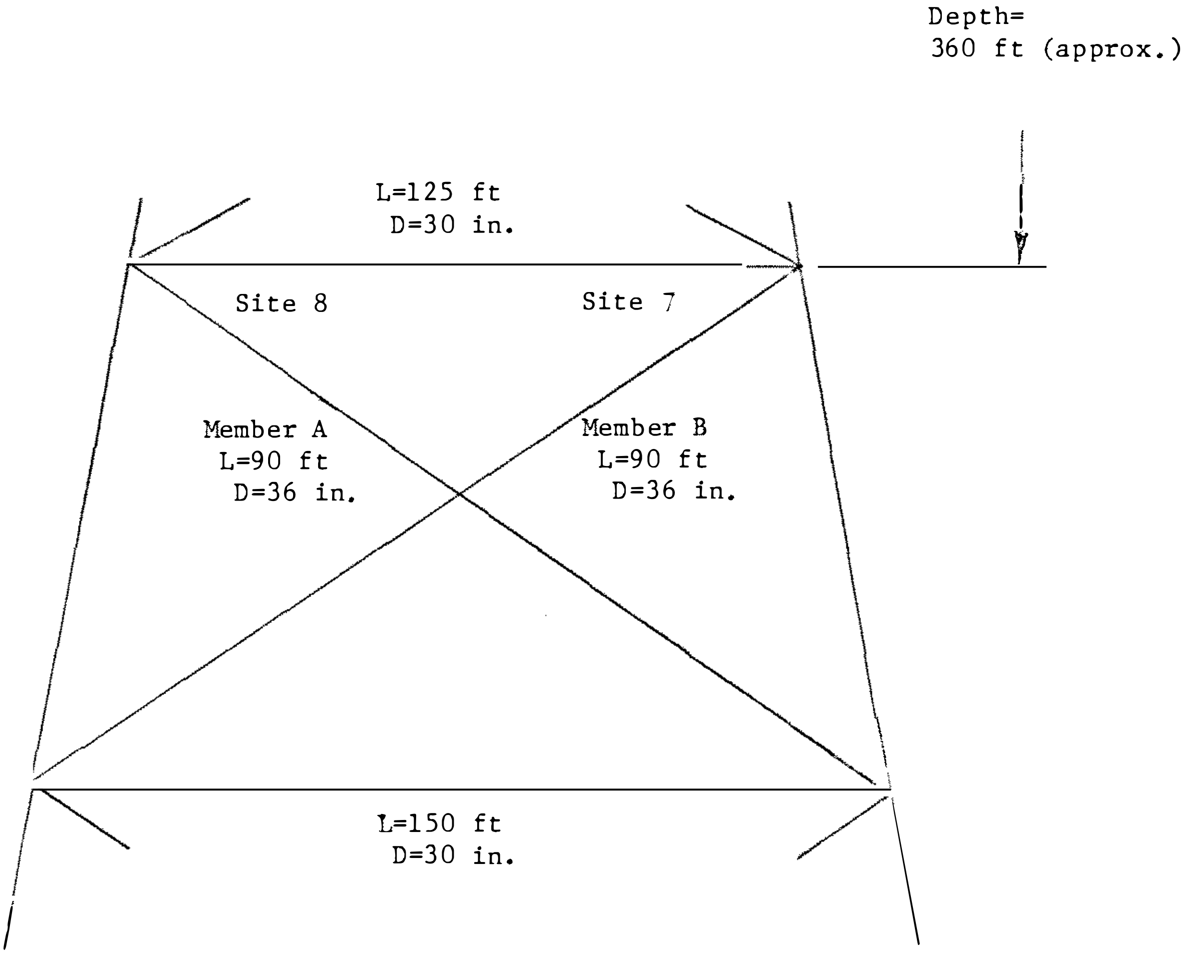


Figure 1. HARVEST platform damage area schematic (not to scale).

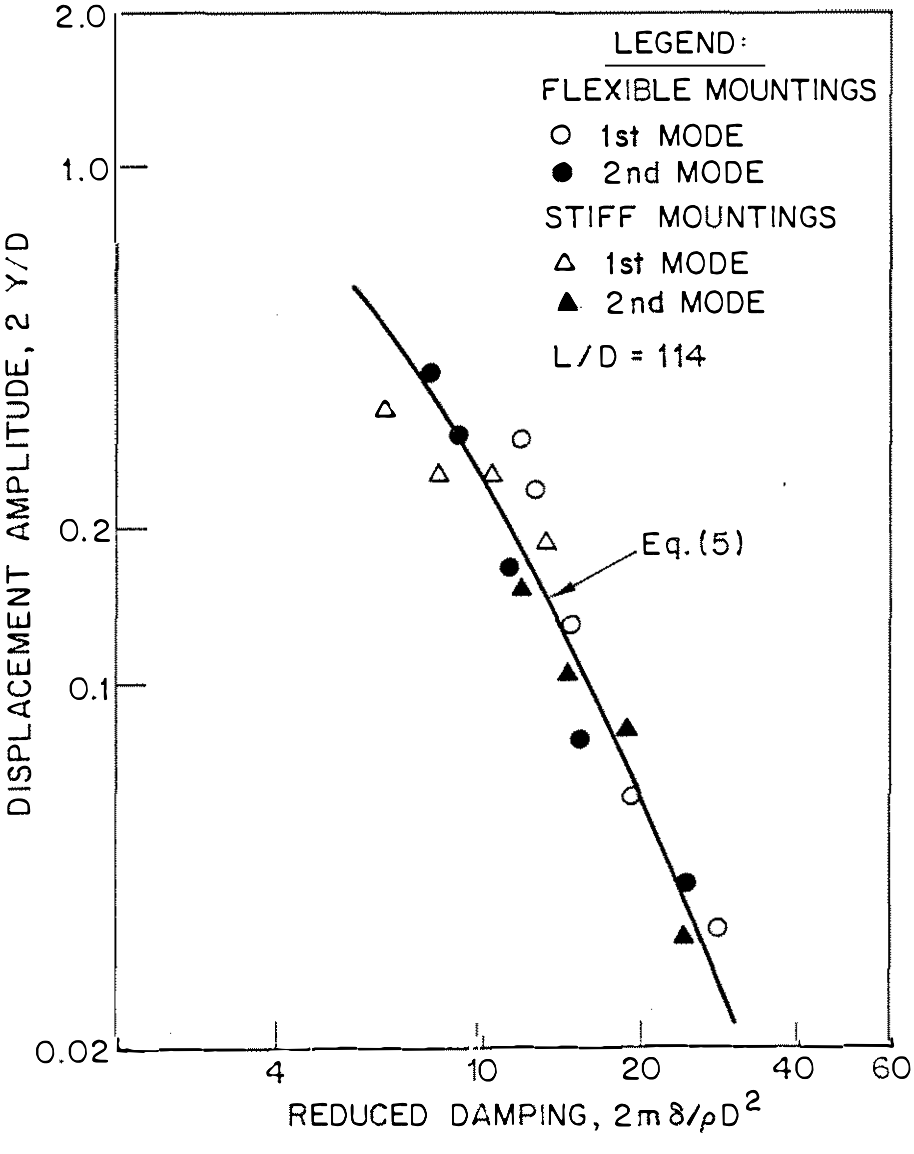
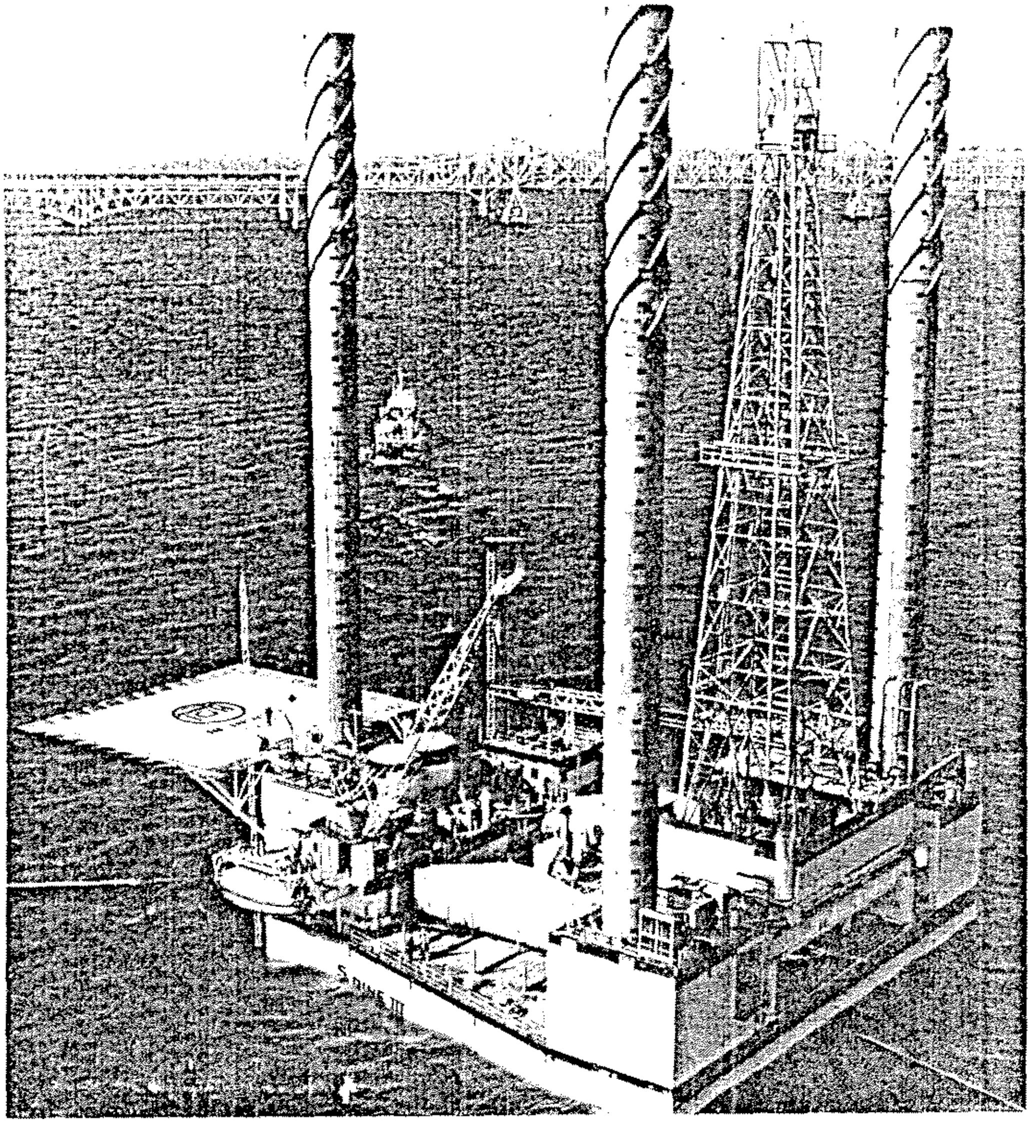


Figure 2. The wind-induced peak-to-peak displacement amplitude due to vortex shedding as a function of the reduced damping; from Griffin (1984).



Bethlehem Steel photograph

Figure 3. A jack-up platform with helical strakes attached to the platform legs to prevent oscillations caused by vortex shedding.

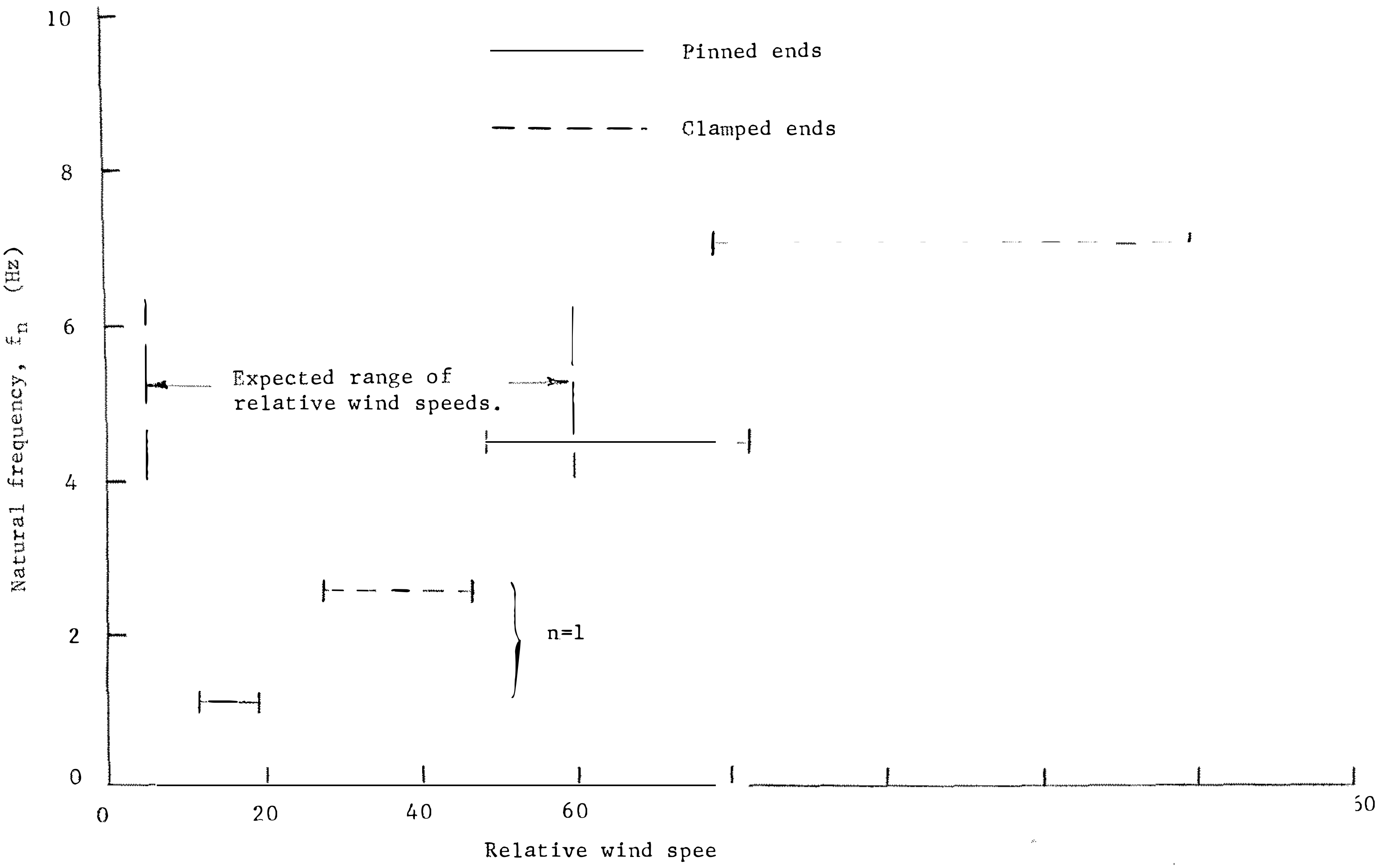


Figure 4. Predicted natural frequencies and relative wind speeds over which vortex shedding-induced vibrations occur.