The MIT/Marine Industry Collegium
Opportunity Brief #30

Dynamic Response of Marine Risers, Tension Legs, Cables and Moorings

A Project of
The Sea Grant College Program
Massachusetts Institute of Technology
MITSG 82-5

MIT/Marine Industry Collegium

Dynamic Response of Marine Risers, Tension Legs, Cables and Moorings

Opportunity Brief #30

Revised Edition

September 1, 1982

The Marine Industry Advisory Services

MIT Sea Grant Program

Cambridge, Massachusetts 02139

MITSG 32-5
Index No. NA 81AA-D-00069/A/M-2

TABLE OF CONTENTS

PREFACE

This Opportunity Brief and the accompanying Workshop (held on December 10, 1981 in Cambridge, MA) were presented as part of the MIT/Marine Industry Collegium Program, which is supported by the NOAA Office of Sea Grant, by MIT and by the more than 100 corporations and government agencies who are members of the Collegium. The underlying studies at MIT were carried out primarily by members of the Ocean Engineering Department at MIT and are more fully reported in the references cited herein. The author is responsible for this abridgement.

Through Opportunity Briefs, Workshops, Symposia, and other interactions the Collegium provides a means for technology transfer among academia, industry and government for mutual profit. For more information, contact the Marine Industry Advisory Services, MIT Sea Grant, at (617) 253-4434.

Norman Doelling
July 15, 1982

1.0 Introduction

Riser systems, tension members of tension leg platforms, and anchor cables are all subject to drag forces and vibration excitation from currents and/or from motions of the drill ship, semi-submersible or tension leg platform which supports them. Since all of these long, flexible, tensioned cylindrical elements are supported only at the sea surface and the sea floor, the possibility of exciting very large vibratory motions (and stresses) is almost certain.

The problem is complex in many ways. First, the mechanical systems are complex. The weight of the riser (unless carefully offset by floatation elements) will cause a variable tension (as a function of depth) and resulting unusual mode shapes. Finite element programs can provide information about mode shapes, but the hydrodynamic excitation forces are not well understood.

At MIT, major efforts are underway to obtain experimental data on the drag forces and dynamic response of riser-like systems subject to steady currents in one case, and to steady currents and surface platform motion in the other.

Drag coefficients for rigid, immobile cylinders in a current are well known. The present investigations are concerned with (1) drag coefficients found when the cylindrical system is forced to vibrate in response to vortex shedding forces; (2) the alternating displacements are in-line with the current flow, and (3) the alternating displacements perpendicular to the current flow.

Prof. Vandiver's work was carried out at Castine, ME, during the summer of 1981 and is being sponsored by the American Bureau of Shipping, Brown and Root, Inc., Chevron Oil Field Research, Conoco Inc., Exxon Production Research, Shell Development Company, Union Oil Research, the Office of Naval Research and the U. S. Geological Survey.

The experiments under Prof. Chryssostomidis' direction are being carried out in a towing tank in Athens, Greece, at the National Technical University. Seed funding for the project has been provided by Sea Grant and is being augmented by Conoco.

2.0 An Experimental Program for the Prediction of the Dynamic Behavior of Riser Type Systems

by: C. Chryssostomidis and N. M. Patrikalakis

Long flexible and tensioned cylindrical members such as risers have always been an important element of offshore systems used in the exploration and production of oil and gas. The design of these subsystems requires the solution of the hydroelastic problem of the motion of a cylinder in a real fluid. Our understanding of this very important offshore engineering problem is incomplete, primarily in the areas of fluid/structure interaction and the force correlation along the cylinder's length.

In order to alleviate part of this problem, an experimental program has been initiated. The fundamental question leading to these experiments is whether the hydroelastic coupling is strong enough to alter the character of the surrounding flow and to give rise to a dynamic behavior, which is significantly different from the one predicted using the rigid cylinder experimental results in a strip-wise manner.

To our knowledge, some of the most sophisticated riser design methodologies available today utilize information from rigid cylinders. There is a strong incentive to be able to use these methodologies because of their simplicity and predictive ability. However, there is a question as to their validity, because by definition they ignore the fluid/structure interaction and force correlation along the cylinder's length.

A detailed scale model of a riser has been built for testing in a towing tank. The riser is supported on the top and bottom by ball joints that limit displacement but do not support torque. The upper end also has a slip-joint so that tension variations are kept as small as possible. In order to simulate platform motion the upper support can be oscillated sinusoidally over a wide range of frequencies. In addition, the oscillation can be set in any direction with respect to the current. The scale model can thus simulate a riser attached to the bottom and to a tension leg platform or semi-submersible anchored in a current. The oscillating motion represents the response of the platform to wave motion.

The present, currently underway, experiments use an aluminum tube covered externally with a sealing material. The overall model characteristics are:

Length between ball joints (L) =	3.000 m
Aluminum tube O.D. (D_o) =	12.61 mm
I.D. (D_i) =	10.92 mm
External Sealing Diameter (D_e) =	15.30 mm
Average mass per unit length (M) =	0.3271 Kg/m
Average effective weight per unit length ($\bar{W}_e$) =	1.378 N/m
Effective overpull at the lower ball joint ($P_e(o)$) =	1.72 N
Bending stiffness of a cross section (EI) =	35.397 Nm^2

The inside of the aluminum tube is filled up with a glycerin solution in water.

The model is instrumented at ten equidistant locations uniformly arranged on the model length, each with two strain gage full bridges installed on the outer surface of the aluminum tube, designed to isolate bending from tension and to measure bending in two perpendicular directions. In addition, the model is instrumented at two extra positions (approximately 85mm from each end) by full bridges specially designed to isolate tension from bending. At a third position (1773 mm, from the lower end) by a full torsion bridge. The mass per unit length of a single wire is 0.198 grams/m and the total volume of all wires is 5.32cm^3. All four wires of each bridge are braided to avoid interference and all wires are sent internally to one end of the model.

All experiments are being conducted in the towing tank of the National Technical Univeristy of Athens, Greece. The complete program involves experiments with 10 frequencies of excitation of the "platform" end, two amplitudes, three current speeds and two directions of alternating motion with respect to current (in line and transverse to it).

The model is not a scaled replica of a particular full-size riser. It is designed to have most non-dimensional parameters assume values which are typical of those found in the field. As noted in Reference 1, certain parameters such as Reynolds number are not representative of field values.

Representation results taken from Reference 1 are shown in Fig. 1. In this instance, the top end of the model is oscillated orthogonally with respect to the current. The strouhal frequency for a fixed cylinder in a current and for the same Reynolds number as in our experiment is 3.2 Hz. The flexible model responds in the lift direction (at 90° with respect to the current) at a "strouhol frequency" equal to 2.2 Hz (rather than the 3.2 Hz that we expected) and the imposed oscillation of the top end (0.5 Hz). Similarly other figures in Ref. 1 indicate dynamic responses at harmonic (and sub-harmonic) frequencies and static levels of strain which cannot be accounted for by "rigid cylinder" theory alone. Further experiments are being carried out to investigate the fluid/structure interaction more clearly.

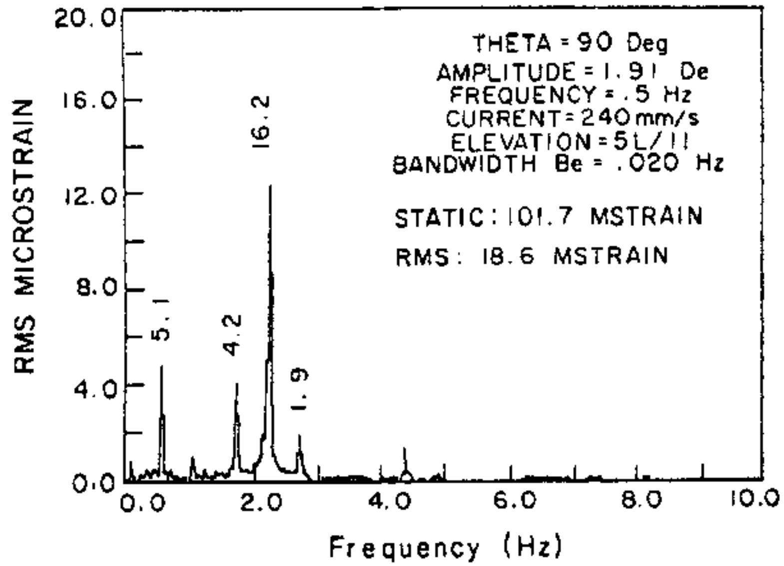

FIGURE 1a: BRIDGE A6 PARALLEL TO CURRENT

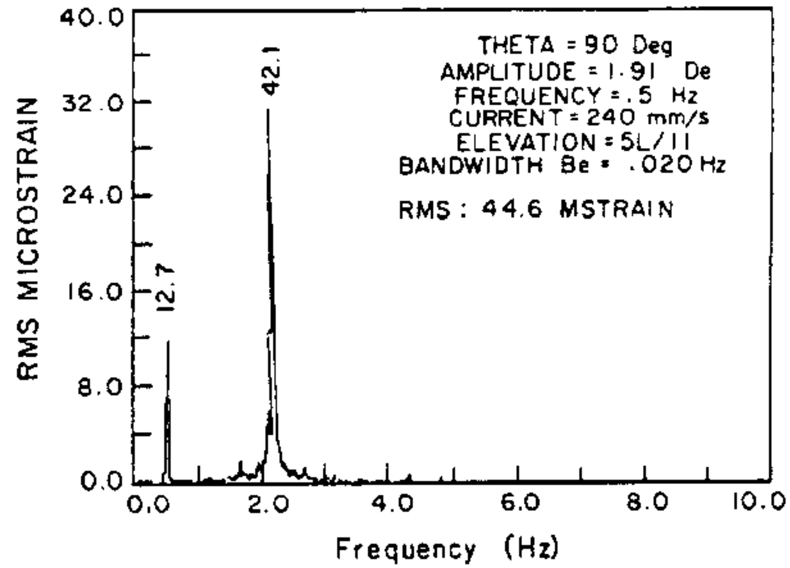

FIGURE 1c: BRIDGE B6 TRANSVERSE TO CURRENT

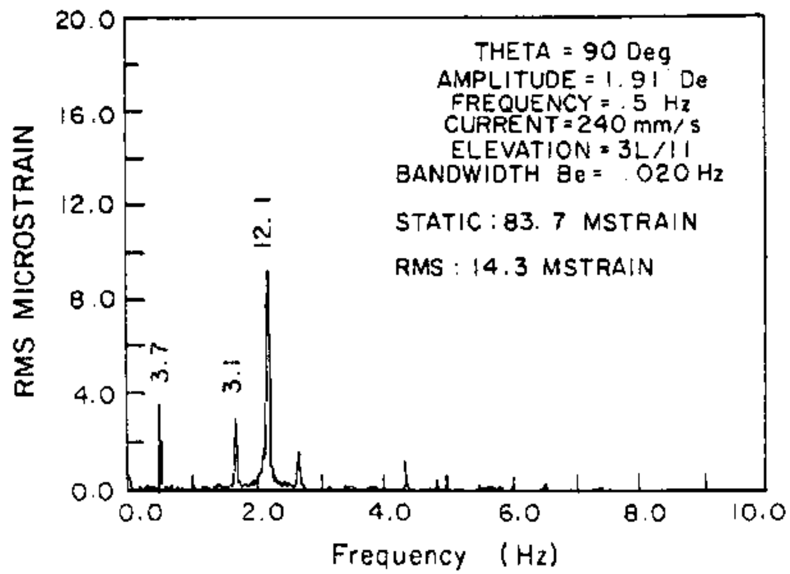

FIGURE 1b: BRIDGE A8 PARALLEL TO CURRENT

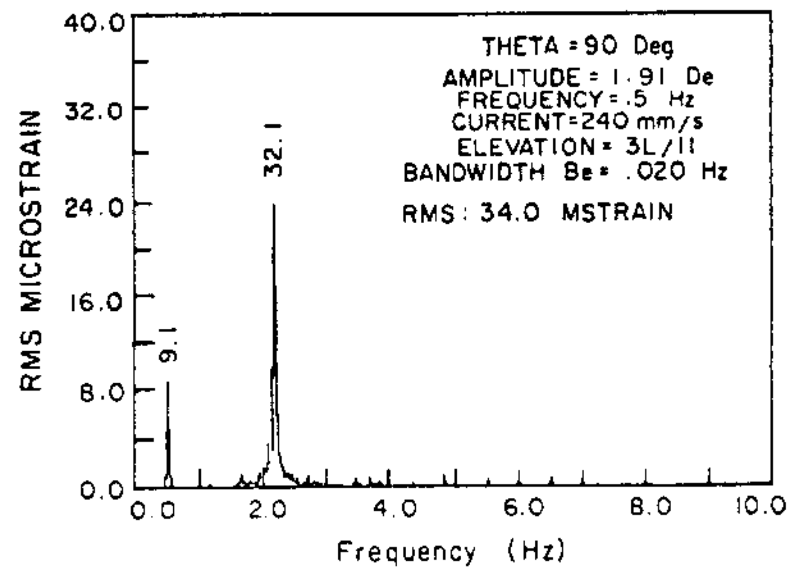

FIGURE 1d: BRIDGE B8 TRANSVERSE TO CURRENT

FIGURE I

3.0 Marine Mooring Statics and Dynamics

by M. Triantafyllou

The consistent formulation of the statics of moorings in water leads to the use of the concept of effective tension. This concept provides suprising results such as sustaining negative actual tension with positive stretch, and the fact that cables are subject to smaller tension than chains, under identical conditions. The modeling of the effects of hydrostatic pressure is demonstrated and efficient schemes to obtain the statics of multi-leg systems are outlined in Reference 2.

The dynamics of cables are very complex since they combine transverse and longitudinal dynamics with completely different time scales. Also, the catenary shape and the elasticity have a significant influence on the natural frequencies. The analytic solutions recently developed at MIT are shown to be consistent with theoretical and experimental results published to date. In the case of catenaries with deep sag, a solution using perturbation techniques is shown to be a very promising tool for multi-leg system dynamic analysis.

In the case of shallow catenaries analysis shows that the ratio of elasticity to catenary effects can change the nature of the solution as confirmed by recent experiments. The solutions developed can be used for preliminary design estimates and to check the accuracy of numerical techniques, especially for accurate modeling of the coupling between transverse and longitudinal dynamics.

Nonlinearities are investigated with particular emphasis on the importance of nonlinear damping. The difference between the response of a cable driven at its upper end and the vortex induced response will be explained on the basis of these results.

The applicability of the theory to the efficient study of multi-leg systems is also discussed and is demonstrated by a specific example of a guyed tower in 1500 feet of water.

4.0 Field Experiments on the Flow Induced Vibration of Long Cylinders

by K. Vandiver

As noted in the Introduction, a series of field experiments were run at Castine, Maine to measure vibration response and drag force on horizontal cylindrical cables exposed to tidal flow which was uniform over the length of the cable. The large tides in Maine allowed the experiments to be set up on a dry sand bar, and provided a convenient range of flow past the cylinder.

The field tests were designed to measure the drag force on long flexible cylinders subject to vortex-induced oscillations. Four different types of cylinders, each 75.0 feet long, were used in the experiments. These cylinders included a uniform cable, a cable with lumped masses, a cable with a vibration suppression fairing, and a steel tube.

Flow velocities ranged from 0 to 2.4 feet/second. Drag force, current, and the horizontal and vertical acceleration of the cylinder at seven locations were simultaneously recorded. In addition, the tension on the cylinder was constantly monitored. From the data taken, drag coefficients and the horizontal and vertical RMS displacements of the cylinders were calculated.

The drag coefficients for the vibrating flexible cylinders are much greater than for stationary rigid cylinders and show a strong dependence on the amplitude of vibration of the cylinder. A typical experimental result is shown in Fig. 2 which is taken from Reference 3.

The horizontal rms velocity profile identifies the "lock-in" regimes. During lock-in the drag coefficient increases substantially and remains high even while the current is decreasing.

Figure 3 is an elegant illustration of the dynamics of a steel pipe vibrating in the lock-in mode. The "figure 8" pattern shows clearly that the horizontal response is at twice the frequency of the vertical response.

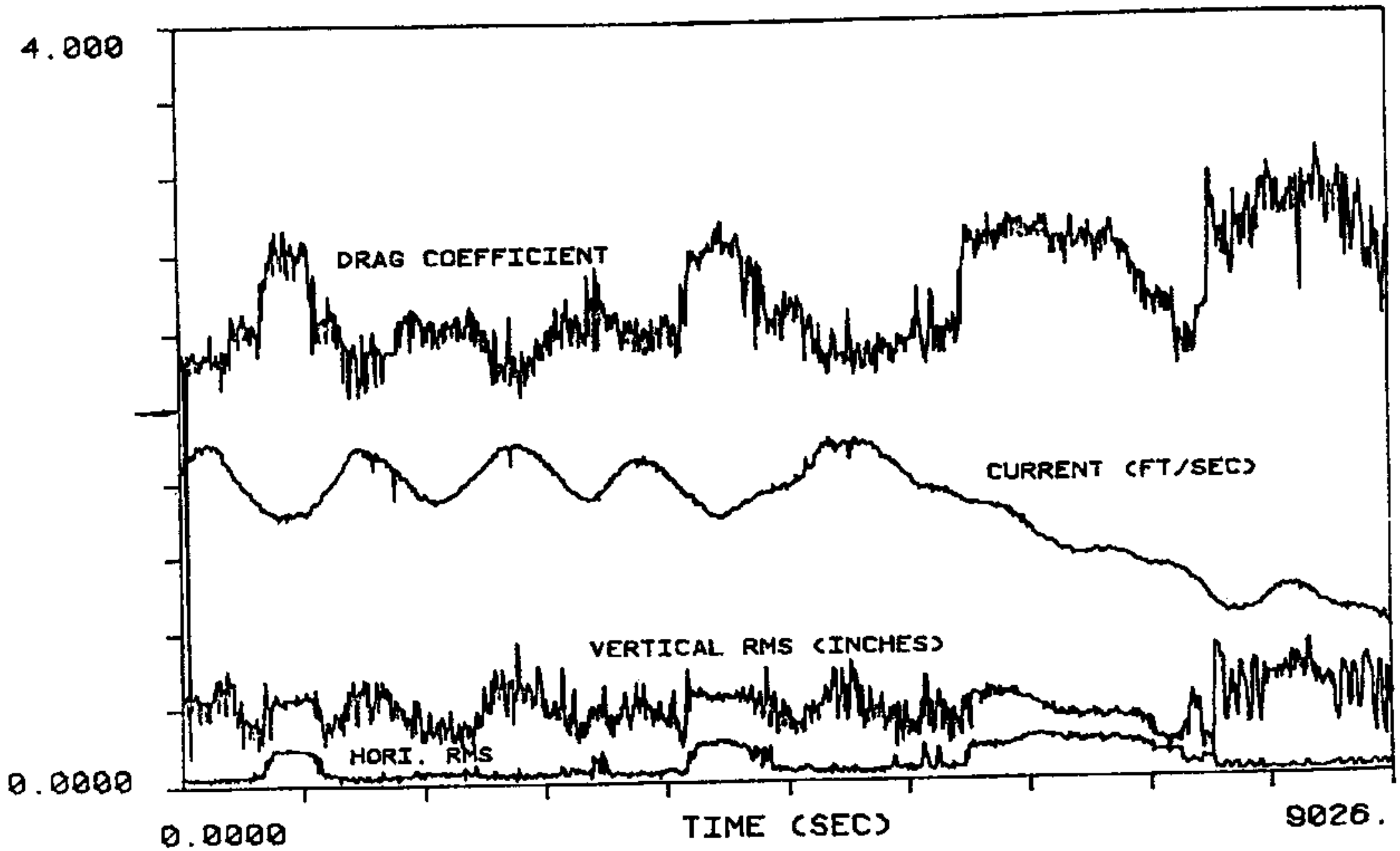

FIG 2 CABLE WITH LUMPED MASSES 10-AUG-81

RMS DATA AT X=3/4 L

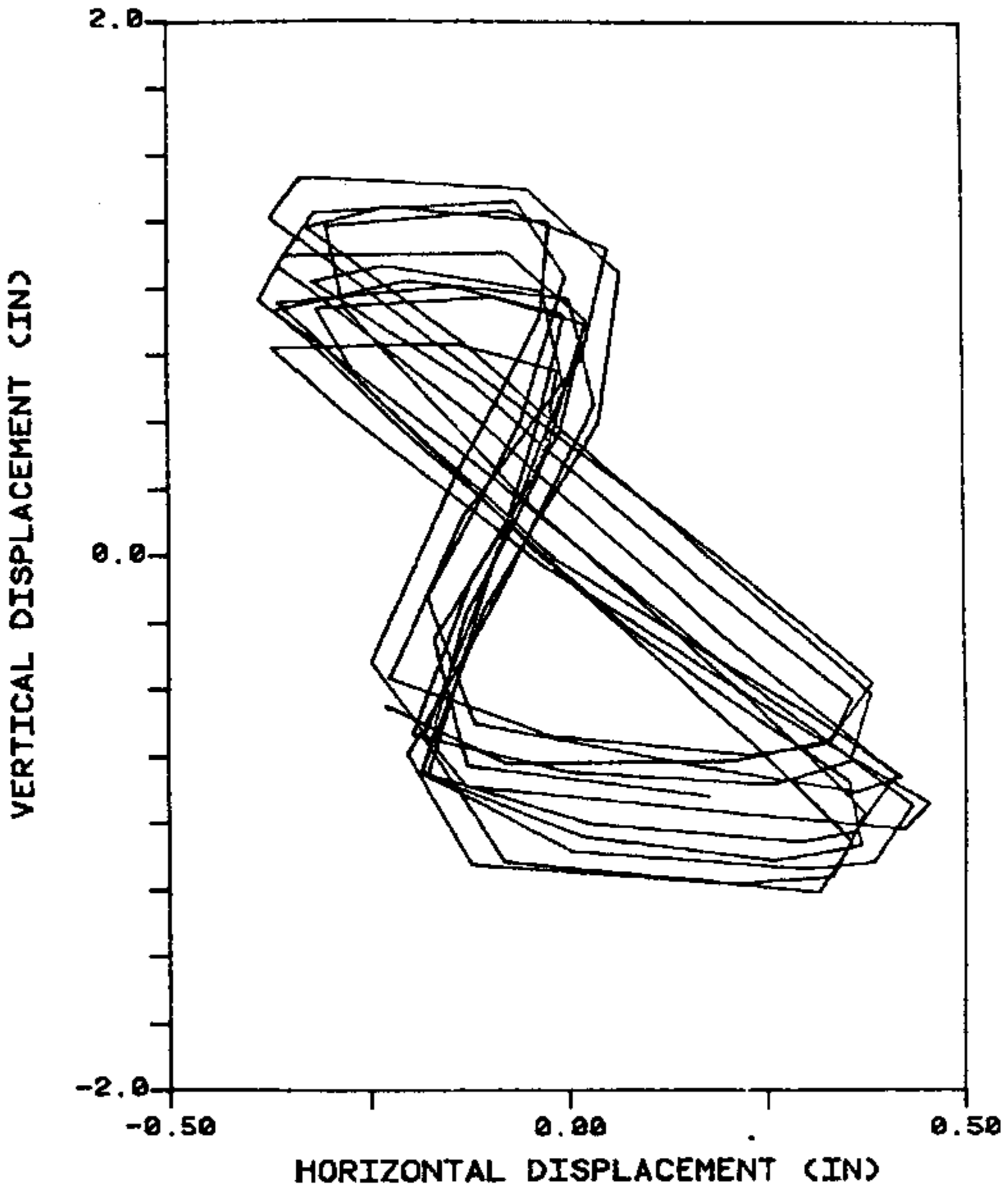

FIGURE 3 LOCK-IN MOTION OF
THE STEEL TUBING AT POSITION L/6.

5.0 REFERENCES

1. Chryssostomidis, C.; Patrikalakis, N. M.
"An Experimental Procedure for the Prediction of the Dynamic Behavior of Riser Type Systems," Proceedings of BOSS '82.

2. Triantafyllou, M.S.; Kardomateas, G.; Bliek, A.
"The Statics and Dynamics of the Mooring Lines of a Guyed Tower for Design Applications," Proceedings of BOSS '82.

3. McGlothlin, J. C.
"Drag Coefficients of Long Flexible Cylinders Subject to Vortex Induced Oscillations," MA thesis, Dept. of Ocean Eng., MIT, January 1982.