

ANALYSIS AND DESIGN OF INSTRUMENTED SUBSURFACE MOORINGV.V.SANIL KUMAR¹, R.N.SAKHARDANDE¹, B.U.NAYAK¹, G.S.SOMANATHA²

1. Ocean Engineering Division, National Institute of Oceanography, Goa.

2 Department of Applied Mechanics and Hydraulics, K.R.E.C. Surathkal.

ABSTRACT

The analysis and design of instrumented mooring is complex, since the environmental loading on the system may be static or dynamic and random. By using certain assumptions, an equivalent static loading system can be adopted and the problem can be simplified. The objective of the present study is to design and analyse single point subsurface instrumented mooring system under a three dimensional current profile. A software 'SUBAM' is developed in FORTRAN-77 and it is applied to analyse a shallow water current meter mooring. The results show that current force has more significant effect on the displacement compared to line tension. The point force due to waves or any other extraneous force has marked effect on the mooring line tension.

1. INTRODUCTION

To design, install and operate any floating/ fixed ocean structures, accurate assessment of environmental loads due to wind, waves and currents is vital. Environmental load determination necessitates collection of site specific time series data for considerably long periods to cover various seasons of the year. Time series data collection can be carried out using satellites, ships etc., but the most recently used procedure is deployment of instrumented mooring system at the specific locations. Moored buoys are also used as marker buoys, navigation buoys in nearshore region.

2. ANALYSIS

The analysis of instrumented mooring is analogous to cable analysis. Three major approaches have been used to describe the behaviour of sea-based cable structures. Two of them subdivide the cable into discrete elements while the other considers the mooring line as a continuum (Webster, 1976). The two discrete element approaches are the lumped parameter and the finite element methods. In the continuum approach, the governing equations are developed considering a differential element of the mooring line with the external and internal fo-

rces acting on it. The analysis of mooring is nonlinear due to (i) The large changes in configuration which the mooring lines undergo in response to applied loads, (ii) The nonlinear load-deformation behaviour of cables, (iii) The drag loading which is a function of the relative velocity squared and (iv) The limiting surface and seafloor constraints which are dependent on the mooring response. The assumptions made to simplify the analysis are; (i) the mooring line is divided into number of segments and the segments are straight between successive nodes. (ii) the instruments are rigid and will not stretch due to tension. (iii) the fluid and structural problems are uncoupled - thus the pressure and velocity fields associated with the fluid motion are unaltered by the presence of the structure. (iv) the flow normal to the cable is independent of the flow tangential to the cable. (v) the current velocity at the centre of segment is assumed constant over the length of segment, (vi) the dynamic behaviour of subsurface buoy due to particle velocity is negligible. (vii) the area of termination is negligible. (viii) only the normal component of drag force is considered in computing the terminal velocity of the anchor.

Theory

Consider a segment 'n' inclined at θ degrees to the vertical and with an azimuth of ϕ degrees (Fig. 1). The velocity of a given point is resolved into two components V_u and V_v . The gravity forces act only in the plane of the segment. Drag forces are considered to be uniform over the length of the segment and are separated into three orthogonal components relative to the axis of the segment (Fig.2); D_{Nv} , normal to the vertical plane of the segment; D_{Nu} , normal to the segment in the vertical plane of the segment; D_T , tangential to the segment.

Under tension, wire ropes elongate by mechanical deformation of the cable structure and by the elastic response of its metallic components. Total elongation is,

$$E_T = \left(\frac{T}{RBS} + \frac{T}{A_w \cdot E} \right) \cdot L_o \quad \dots (1)$$

For synthetic line, the stretch in response to tensile loading is the permanent and elastic elongation and is given by (Berteaux and Chhabra, 1973),

$$E = \left(\frac{T}{d L_p} \right) 1/E_p + \left(\frac{T}{d L_e} \right) 1/E_e \quad \dots (2)$$

Equilibrium equations

The equilibrium condition of each segment is calculated by balancing the gravity and resistive forces against external restraining forces (Fig.3). The equilibrium is attained when the change in inclination and azimuth between successive iteration are negligibly small. From the equilibrium equations the following equations result,

$$T_n = T_{n-1} \cos(\theta^1 - \theta_{n-1}) + D_T + W_T \quad \dots (3)$$

$$\theta_n = \frac{\tan^{-1} (D_{Nv} + W_N - T_{n-1} \sin(\theta_{n-1}^1))}{T_n} + \theta^1 \quad \dots (4)$$

$$\phi_n = \frac{\tan^{-1} (D_{Nu} - T_{n-1} \sin(\theta_{n-1}) \sin(\theta_{n-1}^1))}{T_n \sin \theta_n} + \phi^1 \quad \dots (5)$$

Design

In the design of the mooring system, the instruments has to be placed at specified depths. The software developed is capable of adjusting the lengths of upto ten components, each of which is paired with a depth critical component, (i.e, an instrument).

Based on the elastic equations(1-2) and the equations of equilibrium (3-5) a software 'SUBAM' is developed. In order to illustrate the use of the software and the type of results obtained, a shallow water current meter mooring is designed and analysed for different current profiles and with various point forces acting at the top of the mooring. The details of the mooring is shown in Fig.4.

3.SUMMARY OF RESULTS AND DISCUSSIONS

The mooring line is analysed for different point forces at top, by changing its inclination and with different current profiles. The drag coefficients used for different mooring components are given in Table.1. The mooring line is analysed with no current and no force on top buoy and the results are given in Table 2. It gives the launching transient, reserve buoyancy, tension, excursion etc. of each mooring components. The results indicate that the mooring line remain vertical without any excursion and tension values are approximately equal to the net buoyancy.

The mooring line is considered with a 100 Kg. force acting at 10 degrees to the vertical and 90 degrees azimuth and with a surface current of 30 cm/sec. Fig. 5 shows the input current profile and Fig. 6 shows the resultant mooring line displacement and Table 3. gives the output parameters. Table 4 gives the output parameters for a high surface current of 1.2 m/sec. Fig. 7 gives the variation in component tension for various point forces at top with change in inclination and Fig.8 gives the maximum excursion in the above cases.

The results show that as the current velocity increases the excursion of the mooring system increases. For a surface current of 0.30 m/sec the excursion of the top buoy is 11.73 m. and for 1.2 m/sec surface current the corresponding excursion is 14.86 m. But the change in corresponding line tension is from 137.46 Kg. to 137.03 Kg. However, the point force due to waves or any other extraneous force, acting on the top of the buoy has marked effect on the line tension (Fig. 7). The net buoyancy at the buoy(s) is found to have direct influence on the overall response of the system under different current profiles. Direction of point force relative to currents is found to have significant effect on the mooring line excursion and consequently on the line tension.

4.CONCLUSIONS

To check the validity of the program shallow water moorings are analysed for no external loads which indicated that the moorings remain vertical without any excursion

and the tension values are approximately equal to the net buoyancy as expected. From the results it is concluded that the current forces have more significant effect on the displacements compared to maximum line tension values. The point force, however, has more marked effect on line tension values.

In the present analysis, the specified depths for specified instruments is achieved to an accuracy of 0.5 m. In practice, these results may be further utilised to check every component with regards to its tolerance, breaking characteristics, fatigue properties etc. In case of snapping of any components, the chances of recovery can be estimated directly from the reserve buoyancy results for each of the components.

5. ACKNOWLEDGEMENT

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APPENDIX: LIST OF NOTATIONS

A_w -cross sectional area of wire
 d - diameter of the mooring line
 E - modulus of elasticity
 E_e -exponential coefficient (elastic)
 E_p -exponential coefficient (permanent)
 K -coefficient of structural stretch.
 L_o -measured length of the wire
 L_p -linear coefficient (permanent)
 L_e -linear coefficient (elastic)
 RBS-rated breaking strength of mooring line
 T -axial tension on the wire segment
 T_i -instantaneous tension
 T_m -maximum tension in the history of the line
 W_N -normal component of buoyancy
 W_T -tangential component of buoyancy
 ϕ -inclination of the segment
 θ -azimuth of the segment

APPENDIX: REFERENCES

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TABLE 1 : DRAG COEFFICIENTS FOR MOORING LINE

	WIRE ROPE	SYNTHETIC LINE	CYLINDRICAL	SPHERICAL
NORMAL	1.23	1.23	1.20	0.50
TANGENTIAL	0.01	0.01	0.90	0.14

TABLE 2 : MOORING LINE STATICS

NO.	LENGTH (m)	INCLINATION (Deg.)	TENSION (Kg.)	RESERVE BUOYANCY (Kg.)	DEPTH (m)	EXCURSION (m)	LAUNCHING TRANSIENT (Kg.)
1	1.0	0.0	39.79	31.40	18.24	0.00	50.60
2	5.0	0.0	26.58	18.19	23.44	0.00	37.39
3	1.4	0.0	5.55	2.84	25.01	0.00	20.32
4	11.3	0.0	3.08	5.31	36.51	0.00	17.87
5	1.7	0.0	70.87	62.48	38.41	0.00	103.09
6	1.4	0.0	49.83	41.45	39.98	0.00	86.01
7	5.9	0.0	36.60	28.21	46.10	0.00	72.78
8	2.0	0.0	8.39	0.00	48.30	0.00	44.59
9	1.5	0.0	4.88	0.00	50.00	0.00	41.10

TABLE 3 : MOORING LINE STATICS

NO.	LENGTH (m)	INCLINATION (Deg.)	TENSION (Kg.)	RESERVE BUOYANCY (Kg.)	DEPTH (m)	EXCURSION (m)	LAUNCHING TRANSIENT (Kg.)
1	1.0	17.0	137.46	35.99	18.54	11.73	51.70
2	5.0	15.5	124.69	22.78	23.55	10.34	38.49
3	1.4	13.3	104.14	1.74	25.07	9.98	21.82
4	11.4	13.0	101.72	0.74	36.33	7.36	19.36
5	1.7	36.0	148.53	67.05	37.87	6.24	106.35
6	1.4	31.8	130.24	46.02	39.20	5.42	89.67
7	8.0	27.9	114.48	28.21	46.39	1.47	71.68
8	2.0	22.5	87.91	0.00	48.42	0.63	43.69
9	1.5	21.6	84.64	0.00	50.00	0.00	40.19

TABLE 4 : MOORING LINE STATICS

NO.	LENGTH (m)	INCLINATION (Deg.)	TENSION (Kg.)	RESERVE BUOYANCY (Kg.)	DEPTH (m)	EXCURSION (m)	LAUNCHING TRANSIENT (Kg.)
1	1.0	20.5	137.03	36.23	18.90	14.86	51.75
2	5.0	18.8	124.47	23.02	23.82	13.22	38.55
3	1.4	16.5	104.43	1.98	25.33	12.78	21.89
4	12.5	16.4	101.83	0.74	37.55	9.22	19.21
5	1.7	46.4	139.93	67.05	38.86	7.85	106.28
6	1.4	41.0	124.40	46.02	40.04	6.82	89.63
7	8.0	36.0	109.96	28.21	46.57	1.86	71.83
8	2.0	29.0	84.48	0.00	48.50	0.80	43.64
9	1.5	27.9	81.37	0.00	50.00	0.00	40.15

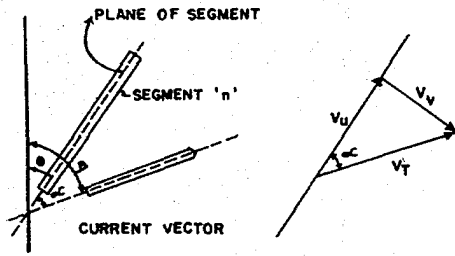


Fig. 1 Components of velocity

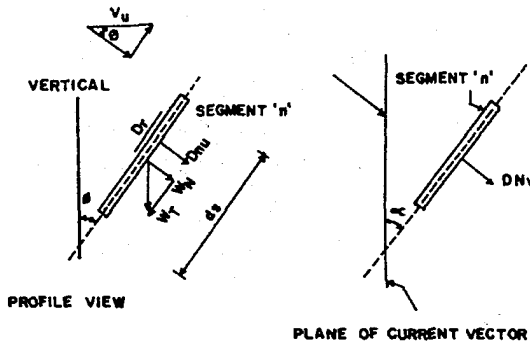
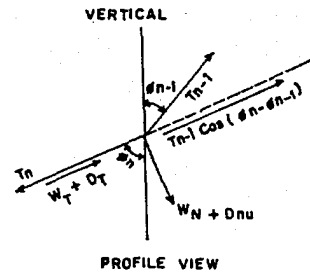


Fig. 2 Forces acting on a segment

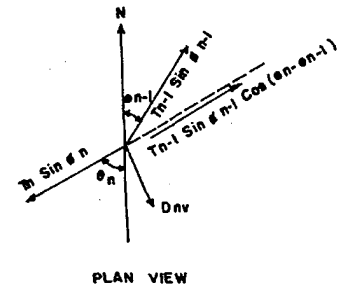


Fig. 3 Equilibrium conditions

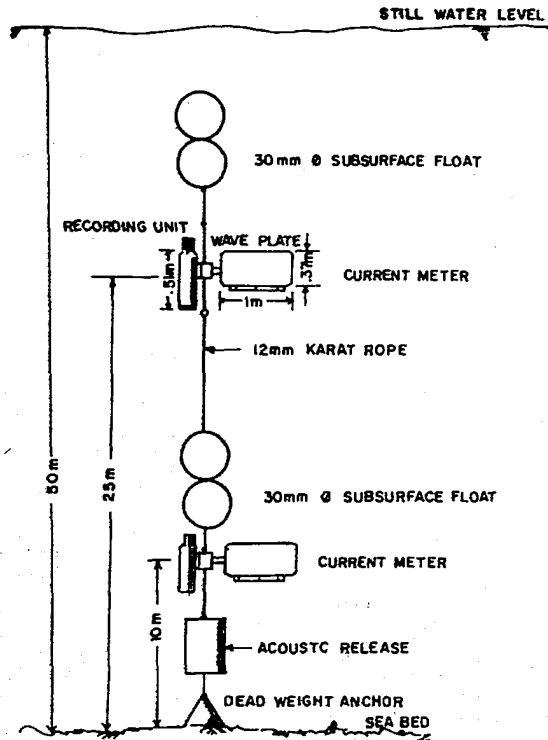


Fig. 4 Shallow water subsurface mooring

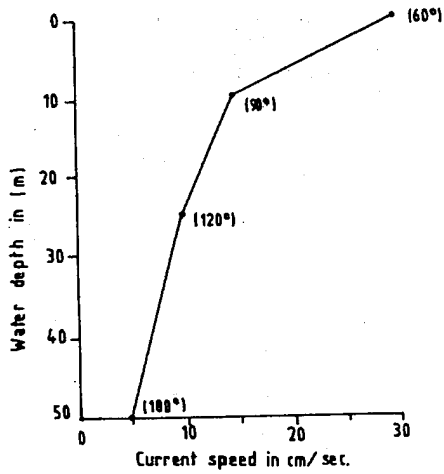


Fig. 5 Current profile No. 1

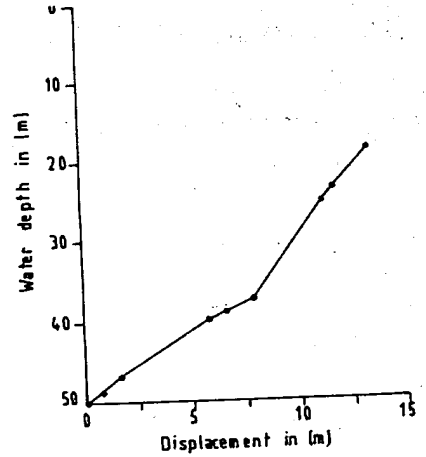


Fig. 6 Resultant displacement of mooring line

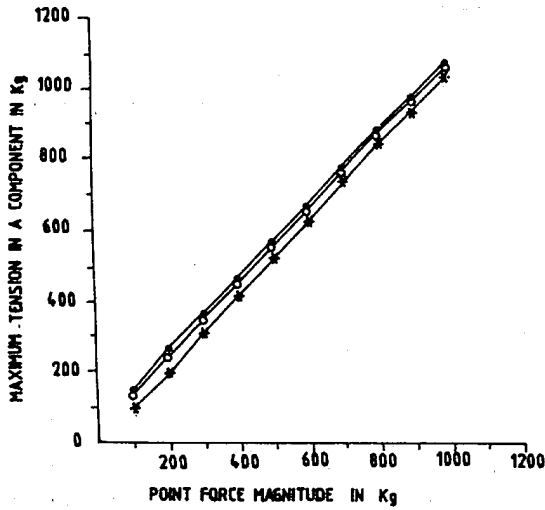


Fig. 7 Variation in component tension for different point force mag and inclination

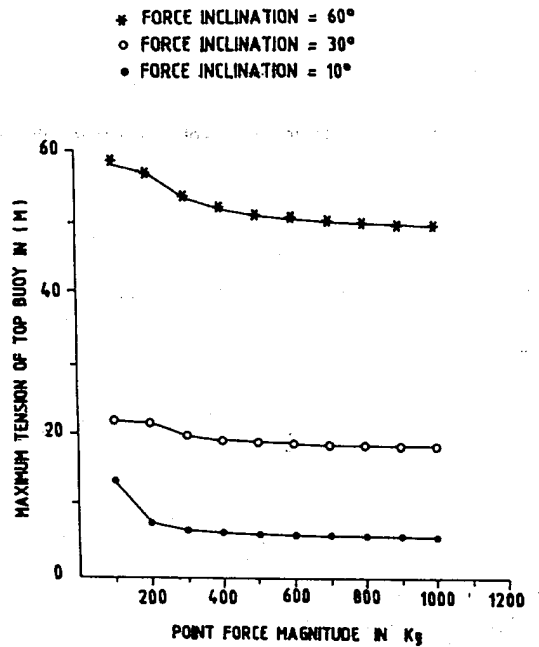


Fig. 8 Excursion of top buoy for different point force mag and inclination