MAKAI OCEAN ENGINEERING, INC.

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MOE-2037-JA
November 04, 1991

Dr. Vince Peterson
High Energy Physics
University of Hawaii

Subject: Results from deployment simulations of DUMAND strings

Dear Dr. Peterson:

The following summarizes our findings, conclusions and recommendations from the simulations we have run for the deployments of the DUMAND strings. A total of 17 runs were carried out to determine:

- The response of the anchor-string to changes in currents and ship position. This analysis was carried out for three different anchor weights and two different types of cables (cable used to lower the strings).
- The response of the anchor to ship motion when the ship is keeping station. This analysis was carried out for different frequencies of ship motion around the station keeping point and different magnitudes of ship excursion.

For these simulations, our Cable Lay Simulator (CLS) was used to model the behavior and loads on the different elements of the string and cable. The overall system was modeled as being composed of 5 elements (see Figure 1). The elements, in order from the bottom up, were:

(1) an anchor
(2) 100 m of Kevlar rope (2 ropes)
(3) 230 m of string with the DUMAND electronic sensors
(4) a buoyancy package
(5) a cable used to lower the string.

The weights, sizes and shapes provided by Peter Gorham and Bob Mitiguy for each of these elements were used to compute equivalent drag and weight per length for each of the cable elements. The 230 m of cable and the electronic sensors were modelled as a 230 m long cable with weight and drag per length equal to the average weight and drag per length of the whole string.

The following summarizes the conclusions of this analysis (a more detailed explanation of the input and output used for these runs and the results obtained are attached at the end of this letter).

CONCLUSIONS AND RECOMMENDATIONS:

1. The response time of the anchor-string to a sudden change in ship position is comparable to the response time of the anchor-string to reasonable changes in ocean currents. A response time of the anchor in the order of 30-40 min is observed for the case in which the ship moves suddenly and the current remains steady. When the ship remains stationary and the current changes, the response time for the anchor is 60 min approximately. Thus, it is possible to control the anchor placement by simply providing proper instructions to the ship, and the changes in anchor position due to changing currents can be neutralized by moving the ship properly. Consequently, the passive method, where the string is controlled from the surface, is a feasible method to deploy the DUMAND strings.

2. Currents acting on the string are more influential that those acting on the cable used to lower the string, due to the increased drag area of the strings. During the deployment of the strings, it would be desirable to measure bottom 400 -500 m of currents in real time. These measurements could be used to predict current trends in the near future which in turn could be used to neutralize the current induced string motions by moving the ship properly ahead of time.

   It is expected that tidal induced currents will be the predominant bottom currents during the deployment of the DUMAND strings. Tidal currents can be predicted quite well, mainly if a current measurement program is set-up in the area of interest ahead of time. The string deployment should take place during days of low tidal activity. Also, it is recommended that, once a string is in place, the next string should be placed approaching the site in the same direction as the bottom current at that time.

3. The anchor-string response to changes in ship position during station keeping show that the amplitude of motion of the anchor is a fraction of the amplitude of the ship motion. The amplitude of anchor motion is a function of the period of ship motion around the station keeping point, and varies between about 20% and 60% of the amplitude of ship motion. From these results, one can estimate that a ship with station keeping capabilities of $\pm$ 20 meters or better should be used to control the string deployment. A ship with somewhat worse station keeping capabilities could be used if more accurate current and ship position measurements and good cable deployment control are used.

Results obtained from these simulations have answered two key questions for the DUMAND project at this stage of development: the passive method, in which the string placement is controlled by moving the ship, is feasible; and the station keeping characteristics of the ship required have been determined. However, one must keep in mind that the simulations run were limited to simple cases in which input data was known exactly. The Cable Lay Simulator (CLS) has the capability of running full simulations of the string placement in real time. In these simulations the operator can include errors associated with the equipment used during the string deployment (ship position errors, current measurement uncertainty, transponder position errors, cable and water property errors, human errors, etc.). These simulations would provide answers in terms of the accuracy of the equipment that needs to be used, type of current measurements to be done, and degree of sophistication needed by the control system used during the deployment. Also, deployment and contingency strategies can be developed and tested.

If you have any questions regarding the enclosed material, please do not hesitate to contact me.

Sincerely,

Jose M. Andres, Ph.D.
Vice president

cc. Dr. John Learned
cc. Dr. Peter Gorham

DUMAND PROJECT:

DESCRIPTION OF TEST RUNS AND RESULTS OBTAINED USING THE CABLE LAY SIMULATOR (CLS).

METHODOLOGY

For these simulations, our Cable Lay Simulator (CLS) was used to model the behavior and loads on the different elements of the string and cable. The overall system was modeled as being composed of 5 elements (see Figure 1). The elements, from the bottom up, were:

(1) an anchor
(2) 100 m of Kevlar rope (2 ropes)
(3) 230 m of string with the DUMAND electronic sensors
(4) a buoyancy package
(5) a cable used to lower the string.

The weights, sizes and shapes provided by Peter Gorham and Bob Mitiguy for each of these elements were used to compute equivalent drag and weight per length for each of the cable elements. The 230 m of cable and the electronic sensors were modelled as a 230 m long cable with weight and drag per length equal to the average weight and drag per length of the whole string.

Table 1 shows the sizes, weight and values of drag coefficients used for the different elements of the string system, as well as the values of some environmental parameters used (density of water, acceleration of gravity, etc.). In this table, the MTU is used to model the buoyancy package located above the string, and the last three blocks of data are for the cable properties associated with the three cables the system is composed of (100 m Kevlar, 230 string and long cable used to lower the string in place).

Table 2 shows pertinent results (loads, segment lengths, position and orientations, etc.) for the string system configuration. The results shown are for the case when a constant current of 5 cm/sec in the X and Y direction is acting on the string system and the ship is at rest. Some description of the symbols used in Table 2 are included to facilitate its understanding.

TEST RUNS:

RUNS 1, 2, 3:

The first three cases analyzed were used to determine the effect of the anchor weight on the response time of the anchor to ship motions. In all these cases, the current acting throughout the water column was zero all the time. The results obtained are summarized in Figures 2 and 3. As shown in Figure 2, at t=0, the ship was at rest, and the cable hanging vertically down since drag forces were zero (no currents). At t=30 minutes, the ship moved eastward (+X-coordinate) at a speed of 30 m/min (1 knot approx.) for 5 min. (a total of 150 meters). This is shown by a continuous line in Figure 3. The dotted lines in Figure 3 show the response of the anchor to this motion. It can be seen that as the weight of the anchor increases, the response of the anchor is faster. For an anchor weight of 19,000 N, as planned for the DUMAND project, the anchor completes 90 % of the ship motion in 35 to 45 minutes.

Figures 4, 5 and 6 show profiles of the cable-string system as a function of time for different anchor weights (19,000 N, 9,500 N and 2,500 N, respectively). In these figures, the ship position at different times has been indicated by triangles and smaller rectangles at depth=0, the dotted line show the cable shape as a function of depth, the buoyancy package is indicated by the solid triangle, and finally the anchor is indicated by the X symbol. It is clear from these figures that the response time of the anchor-string system to changes in ship position is shorter for heavier anchors.

RUNS 4, 5:

These cases deal with the response time of the anchor to changes observed in the currents. For these runs the ship remains stationary but the current in the X- and Y- direction changes in time. For t<30 min, the current in the X- and Y- direction is constant and equal to 3 cm/sec throughout the water column, and for t>30, the value of the current in the X- and Y- direction changes at a rate of 0.1 cm/sec/sec (see Figure 7). This value of rate of change used is close to the maximum values that would be expected for tidal induced currents in the area of interest.

The results from runs 4 and 5 are shown in Figure 8. Run 4 was done using an anchor weight of 19,000 N, while run 5 uses an anchor weight of only 2,500 N. The results show that the lighter the anchor the faster it is moved by the currents. By comparing the results from runs 4 and 5 with those from runs 1 and 3 respectively, one sees that using a heavier anchor increases the response time due to currents and decreases the response time due to changes in ship position.

Figures 9 and 10 show profiles of cable-string system at different times for two different values of anchor weights. In these figures, the ship position at different times has been indicated by a triangle at depth=0, the dotted line shows the cable shape as a function of depth, the buoyancy package is indicated by solid triangles, and finally the anchor is indicated by the X symbol. It is clear from these figures that light anchors can be moved by currents faster and farther than heavier anchor.

RUN 6:

This run was carried out to estimate the effect of current measurement uncertainty as a function of the water depth. A current pulse, 500 m wide and 5 cm/sec in magnitude in the X- and Y- direction, is used to determine changes in anchor position after steady state has been reached. This is done for different values of pulse depth. As shown in Figure 11, a constant current of 5 cm/sec acting on the system deflects the anchor about 72 m. As the pulse travels downwards, the anchor displacement increases. Near the bottom the current pulse is able to move the anchor considerably more than near the surface. This is mainly due to the increased drag surface area due to the sensors attached to the string. From these results it is obvious that to position the anchor on a given location, it is more important to know the bottom currents than the surface currents.

RUNS 7, 8:

Runs 7 and 8 are similar to runs 4 and 5, respectively, but now instead of using a time varying current, a step change in the current near the bottom is used. As shown in Figure 12, the current in the X- and Y- direction is 5 cm/sec for $t<30$ min, and for $t>30$ min the current below 4,000 m doubles in magnitude. Results from these runs are shown in Figures 13 and 14. The results shown that the current will deflect more the system with the lighter anchor. Also, the response time is in the order of 60 min, which is somewhat smaller than the response times obtained for the same anchor weights for a change in ship position (runs 1 and 3).

By comparing these results with the results from runs 1 and 3, and assuming that the changes in currents used in these simulations are realistic, one can see that by moving the ship it is possible to compensate current induced motions of the anchor. Of course, a straightforward comparison of these cases does not include the fact that changes in currents could be predicted to a certain degree, and therefore, one could improve significantly the control of the anchor position from the surface.

RUNS 9 & 10:

Runs 9 and 10 are similar to runs 4 and 1 respectively (weight of anchor is 19,000 N), but now a different cable is used. For these runs, the same anchor, string and buoyancy package as those used in all the other simulations were used, but now the cable used to lower the string has been modified. Instead of using 4,500 m of 1" poly. rope, 300 m of the same 1" poly. rope and 4,200 m of 1/2" wire rope (3x19, torque balanced cable with a breaking strength of 26,000 lb) are used. The short section of poly. rope attached to the buoyancy package is used to absorb some of the large dynamic tensions that can develop during the early stage of string deployment. The heavier 1/2" wire rope is used to increase the weight to drag ratio of the cable, and therefore, decrease the total string excursion induced by currents. The results given in Figure 15 are for the case when the ship is stationary and the X- and Y- bottom currents change at t=30 min from 5 cm/sec to 10 cm/sec (see Run 4), while the results given in Figure 16 are for the case when the current is zero and the ship moves between t=30 min and t=35 min at a speed of 30 m/min (see Run 1). These results show that by properly selecting the components the cable is made of, one can minimize the drag on the system. This will decrease the excursion of the string due to changes in currents, and therefore, improve the degree of control in the string deployment.

RUNS 11, 12, 13, 14:

These runs have been designed to estimate the anchor excursion that could be expected when the ship is trying to keep station around an X,Y point at the surface.
The results for run 11 are shown in Figures 17 and 18. Figure 17 shows a plan view of the ship position as a function of time, while Figure 18 shows the resulting anchor motion due to those changes in ship position. In these figures, the asterisks represent ship and anchor positions every consecutive minute. These figures depict a case in which the ship is able to keep station within $\pm$ 80 meters and the ship completes a loop (period of ship motion around station keeping point) in about 40 to 45 min. As we can see, the maximum anchor excursion is about 55% to 60% of the amplitude of ship motion.

Results from run 12 are shown in Figures 19 and 20. These figures are similar to Figures 17 and 18, but now the period of ship motion is only about 15 minutes, instead of the 40-45 min used for Run 11. In this case, the maximum excursion for the anchor is only about 35% of the amplitude of ship motion.

Figures 21 and 22 depict the results for run 13. These figures are similar to Figures 19 and 20, but now the period of ship motion is only about 7 minutes, half of that used in run 12. Also, in these figures the asterisks represent the ship and anchor position every consecutive 30 sec, instead of the 1 min used in previous runs. In this case, the maximum excursion for the anchor is further reduced to about 25% of the amplitude of ship motion.

Figures 23 and 24 depict the results for run 14. This run was carried out selecting a an amplitude of ship motion of about $\pm$ 25 m and a period of 6 to 7 minutes. This is a more realistic representation of what a ship with a relatively simple Dynamic Positioning (DP System could do. The results from these figures show that as in the case of run 13, the maximum excursion for the anchor is only about 25% of the amplitude of ship motion.

From the previous results one can see that the ratio of anchor excursion to amplitude of ship motion is a function of the frequency of ship motion around the station keeping point and is not a function of the amplitude of ship motion itself. The results
from runs 11, 12 and 13 show that the maximum excursion of the anchor decreases as the frequency of the ship motion around the station keeping point increases. Then, during the deployment of the DUMAND strings it is desirable for the ship to maneuver constantly around the station keeping point, in order to filter out some of the anchor motions.

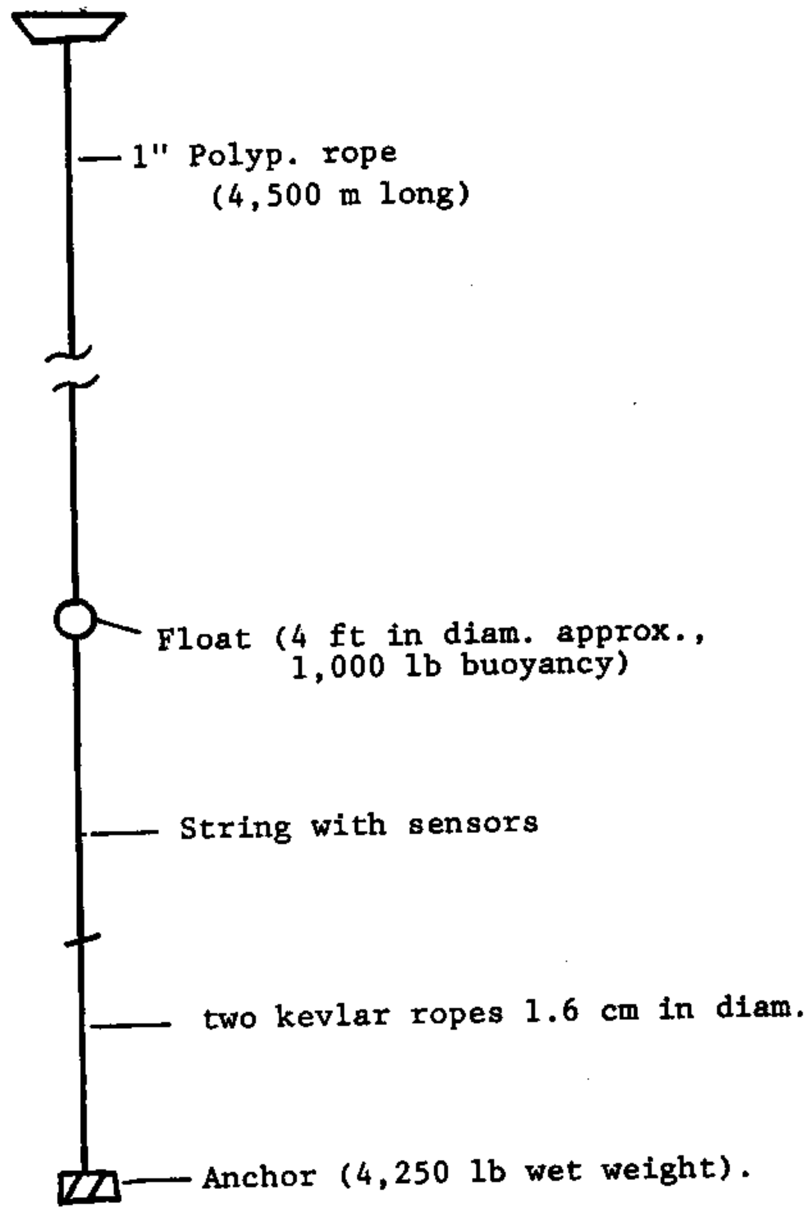
RUNS 15, 16, 17:

These three runs are used to determine how the anchor response time is affected when the ship performs a series of maneuvers consecutively. For all these runs, the current was constant and equal to zero. Run 15 depicts the case where the ship was at rest for $t<30$ min, and the cable hanging vertically down since drag forces were zero (no currents). At $t=30$ minutes, the ship moved eastward (+X-coordinate) at a speed of 30 m/min (1 knot approx.) for 5 min (a total of 150 meters), then it stops for 5 more min, and finally comes back to its original position at the speed of 30 m/min (see Figure 25). In Figure 26, the ship position (continuous line) and the resultant anchor position (dotted line) are presented as a function of time. Also, Figure 27 shows profiles of the cable-string system as a function of time.

Run 16 is similar to run 15 but now the ship does not stop for 5 min, but instead moves 150 m in the +X direction in 5 min and then returns to its original position at the same speed of 30 m/sec (see Figure 28). The resultant anchor and cable responses can be observed from Figures 29 and 30. By comparing the results from runs 15 and 16, one can see that the magnitude of the anchor displacement can be modified considerably depending on the time at which the ship instructions are executed. The Integrated Control System (ICS) used by Makai has the capability to look into the future and determine the expected response of the anchor for different ship instructions.

Finally, run 17 combines a ship motion in the +X direction for 5 minutes with a 10 min motion in the +Y direction (see Figure 31). The results for this run are presented in Figures 32 and 33. Note that as soon as the ship motion becomes more complex (in the XY plane) than in the previous cases analyzed, it becomes more difficult for a human to estimate the anchor displacement as a function of time. The use of a simplified control system facilitates this task enormously.

FIGURE 1. BASIC CABLE-STRING CONFIGURATION
(not to scale)



```
-------------WATER AND GLOBAL PROPERTIES
    1035.00000000    rhow (kg/m^3)
       1.17000000    xnu  (mm^2/s)
       9.78000000    grav (m/s^2)
       0.7           bottom friction coeff
--------------ANCHOR-------------------
       1.00          anchor diameter (meters)
       1.00          anchor segment length (m)
     19000.          anchor weight  (N/m)
       0.8           anchor Cd
----------------MTU--------------------
       1.0           length of MTU unit (meters)
       1.16          diameter of MTU unit (meters)
     -4450.0         wet weight of MTU unit (N/m)
       1.2           drag coefficient of MTU unit
----------------REPEATER--------------------
       3.0           length of REPEATER unit (meters)
       0.3584        diameter of REPEATER unit (meters)
       100.0         wet weight of REPEATER unit (N/m)
       1.0           drag coefficient of REPEATER unit
----------------TRANSPONDER-------------------
       0.1           length of TRANSPONDER unit (meters)
       0.3584        diameter of TRANSPONDER unit (meters)
       000.0         wet weight of TRANSPONDER unit (N/m)
       1.0           drag coefficient of TRANSPONDER unit
---------------CABLE PROPERTIES--------------
        3            Number of different types of cable

      100.0          Maximum S from cable end
      .03200         diameter (m)
      20.00          maximum segment length
      1.250          wet weight (N/m)
      1.5            Cd
      1.0            fullness coefficient

      330.0          Maximum S from cable end
      .1300          diameter (m)
      30.00          maximum segment length
      37.20          wet weight (N/m)
      1.6            Cd
      1.0            fullness coefficient

    24800.0          Maximum S from cable end
      .025400        diameter (m)
     300.00          maximum segment length
     -0.276          wet weight (N/m)
      1.4            Cd
      1.0            fullness coefficient

NOTES:  Bottom friction (BOTTOM) uses weight of cable #1
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TABLE 1.

SUMMARY OF CABLE SHAPE at 000:00:00 for drag=ini

PROPERTIES AND CONSTANTS
rhow= 1035.00 kg/m^3 xnu= 1.1700 mm^2/s grav= 9.7800 m/s^2
Error tolerance (eps)= .100000E-08 Solution accuracy (acc)= .100000E-05 Tolc = 5.000000
Cable and MTU properties...Npr= 3

i	ds	Diam	Cd	wtwet	rho	wtdry	voidf	Area
C1	20.000	.032000	1.500	1.250000	1193.921011	9.390837	1.00000	.00080425
C2	30.000	.130000	1.600	37.200000	1321.567872	171.555606	1.00000	.01327323
C3	300.000	.025400	1.400	-.276000	979.305423	4.853045	1.00000	.00050671
A1	1.000	1.000000	.800	19000.000000				
M1	1.000	1.160000	1.200	-4450.000000				
R1	3.000	.358400	1.000	100.000000				
T1	.100	.358400	1.000	.000000				

← CABLE PROPERTIES

idyn= 0 Tangential drag not included Centripetal accelerations not included

Us= .000000 Bs= .0000 Vc= .000000 dt= 0 kerr=000000 errflg= F
TD= F fb= 1.0000 slk= .0000 dSb= .000 ipath= 0 ipage= 0 izmtu= 1 Sbmtu= .0000

loc	m	mopt	time	S	T	A	B	X	Y	Z
00	0	0	000:00:00	.000	.000	.000	.000	391061.000	75044.000	4800.000
0	0	0	000:00:00	.000	.000	.000	.000	391061.000	75044.000	.000
bot	1	8	000:00:00	.000	.000	.000	.000	391061.000	75044.000	4800.000
top	1	8	000:00:00	4805.603	21.995	88.559	-135.000	391011.584	74994.584	-5.000
topp	1	8	000:00:00	4805.603	21.995	88.559	-135.000	391011.584	74994.584	-5.000

TABLE 2.

Ssus= 4805.603 Xsus= -49.416 Ysus= -49.416 Lead= -49.416 Kite= 49.416

ANCHOR

SEGMENT SUMMARY from OUT3 ...time=000:00:00 m= 1 Nsegs= 31 mopt= 8 TD= F Ntiter= 125 idyn= 0

m	n	type		ds	Sts	Tts	Ats	Bts	Xts	Yts	Zts	Vtsx	Vtsy	Vtsz	gnx	gny	gnz
1	0	X0	0	.00	.00	.000	.000	.000	391061.00	75044.00	4800.00	.0000	.0000	.0000	.000	.000	.000
1	1	A1	1	1.00	1.00	19.000	89.994	-135.000	391061.00	75044.00	4799.00	.0000	.0000	.0000	1.464	1.464	.000
1	2	C1	0	20.00	21.00	19.025	89.986	-135.000	391061.00	75044.00	4779.00	.0000	.0000	.0000	.088	.088	.000
1	3	C1	0	20.00	41.00	19.050	89.979	-135.000	391060.99	75043.99	4759.00	.0000	.0000	.0000	.088	.088	.000
1	4	C1	0	20.00	61.00	19.075	89.971	-135.000	391060.99	75043.99	4739.00	.0000	.0000	.0000	.088	.088	.000
1	5	C1	0	20.00	81.00	19.100	89.964	-135.000	391060.98	75043.98	4719.00	.0000	.0000	.0000	.088	.088	.000
1	6	C1	0	19.00	100.00	19.124	89.957	-135.000	391060.97	75043.97	4700.00	.0000	.0000	.0000	.088	.088	.000
1	7	C2	0	30.00	130.00	20.240	89.914	-135.000	391060.95	75043.95	4670.00	.0000	.0000	.0000	.381	.381	.000
1	8	C2	0	30.00	160.00	21.356	89.875	-135.000	391060.91	75043.91	4640.00	.0000	.0000	.0000	.381	.381	.001
1	9	C2	0	30.00	190.00	22.472	89.840	-135.000	391060.85	75043.85	4610.00	.0000	.0000	.0000	.381	.381	.001
1	10	C2	0	30.00	220.00	23.588	89.808	-135.000	391060.79	75043.79	4580.00	.0000	.0000	.0000	.381	.381	.002
1	11	C2	0	30.00	250.00	24.704	89.779	-135.000	391060.71	75043.71	4550.00	.0000	.0000	.0000	.381	.381	.002
1	12	C2	0	30.00	280.00	25.820	89.753	-135.000	391060.63	75043.63	4520.00	.0000	.0000	.0000	.381	.381	.002
1	13	C2	0	30.00	310.00	26.936	89.729	-135.000	391060.53	75043.53	4490.00	.0000	.0000	.0000	.381	.381	.002
1	14	C2	0	20.00	330.00	27.680	89.714	-135.000	391060.46	75043.46	4470.00	.0000	.0000	.0000	.381	.381	.003
1	15	C3	0	44.50	374.50	27.667	89.705	-135.000	391060.30	75043.30	4425.50	.0000	.0000	.0000	.065	.065	.000
1	16	M3	2	1.00	375.50	23.218	89.640	-135.000	391060.30	75043.30	4424.50	.0000	.0000	.0000	2.547	2.547	.019
1	17	C3	0	300.00	675.50	23.135	89.570	-135.000	391058.84	75041.84	4124.51	.0000	.0000	.0000	.065	.065	.001
1	18	C3	0	300.00	975.50	23.052	89.500	-135.000	391057.12	75040.12	3824.52	.0000	.0000	.0000	.065	.065	.001
1	19	C3	0	300.00	1275.50	22.969	89.430	-135.000	391055.14	75038.14	3524.53	.0000	.0000	.0000	.065	.065	.001
1	20	C3	0	300.00	1575.50	22.886	89.358	-135.000	391052.89	75035.89	3224.55	.0000	.0000	.0000	.065	.065	.001
1	21	C3	0	300.00	1875.50	22.804	89.287	-135.000	391050.38	75033.38	2924.57	.0000	.0000	.0000	.065	.065	.001
1	22	C3	0	300.00	2175.50	22.721	89.215	-135.000	391047.61	75030.61	2624.60	.0000	.0000	.0000	.065	.065	.001
1	23	C3	0	300.00	2475.50	22.638	89.142	-135.000	391044.57	75027.57	2324.63	.0000	.0000	.0000	.065	.065	.001
1	24	C3	0	300.00	2775.50	22.555	89.069	-135.000	391041.25	75024.25	2024.66	.0000	.0000	.0000	.065	.065	.001
1	25	C3	0	300.00	3075.50	22.473	88.995	-135.000	391037.67	75020.67	1724.71	.0000	.0000	.0000	.065	.065	.001
1	26	C3	0	300.00	3375.50	22.390	88.920	-135.000	391033.81	75016.81	1424.76	.0000	.0000	.0000	.065	.065	.002
1	27	C3	0	300.00	3675.50	22.307	88.846	-135.000	391029.68	75012.68	1124.81	.0000	.0000	.0000	.065	.065	.002
1	28	C3	0	300.00	3975.50	22.224	88.770	-135.000	391025.26	75008.26	824.88	.0000	.0000	.0000	.065	.065	.002
1	29	C3	0	300.00	4275.50	22.141	88.694	-135.000	391020.57	75003.57	524.95	.0000	.0000	.0000	.065	.065	.002
1	30	C3	0	300.00	4575.50	22.059	88.618	-135.000	391015.59	74998.59	225.03	.0000	.0000	.0000	.065	.065	.002
1	31	C3	0	230.10	4805.60	21.995	88.559	-135.000	391011.58	74994.58	-5.00	.0000	.0000	.0000	.065	.065	.002

BUOYANCY PACKAGE

TOP SEGMENT — SEGMENT LENGTH — TENSION (Newtons) — X, Y & Z COORDINATES (METERS) — RELATIVE CABLE SEGMENT VELOCITIES — DRAG FORCES/LENGTH

ANCHOR RESPONSE TO CHANGES IN SHIP POSITION

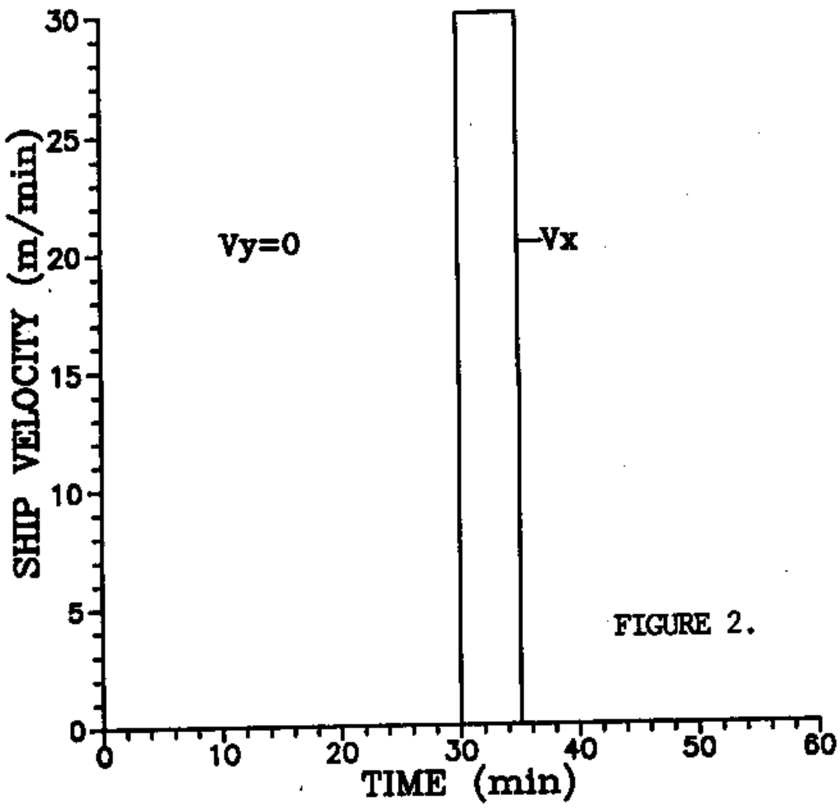


FIGURE 2.

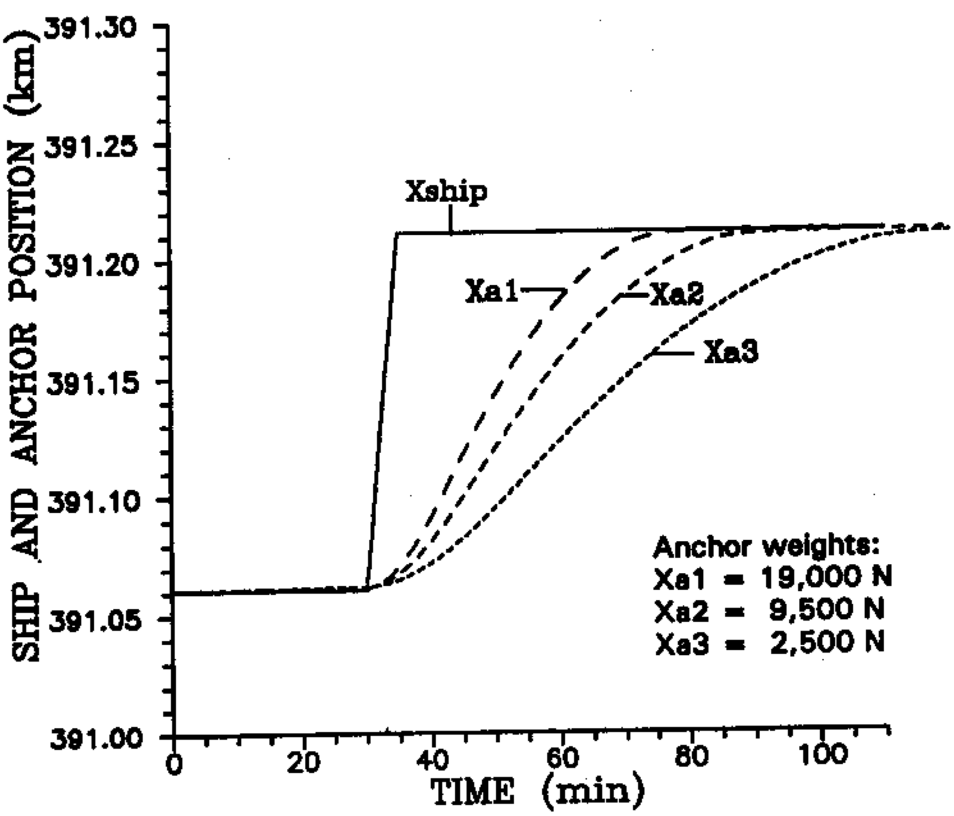


FIGURE 3. Anchor response to changes in ship position.

FIGURE 4. Run Test #1: System response to changes in ship position (Anchor weight=19,000 N) Tue Oct 15 12:11:03 1991

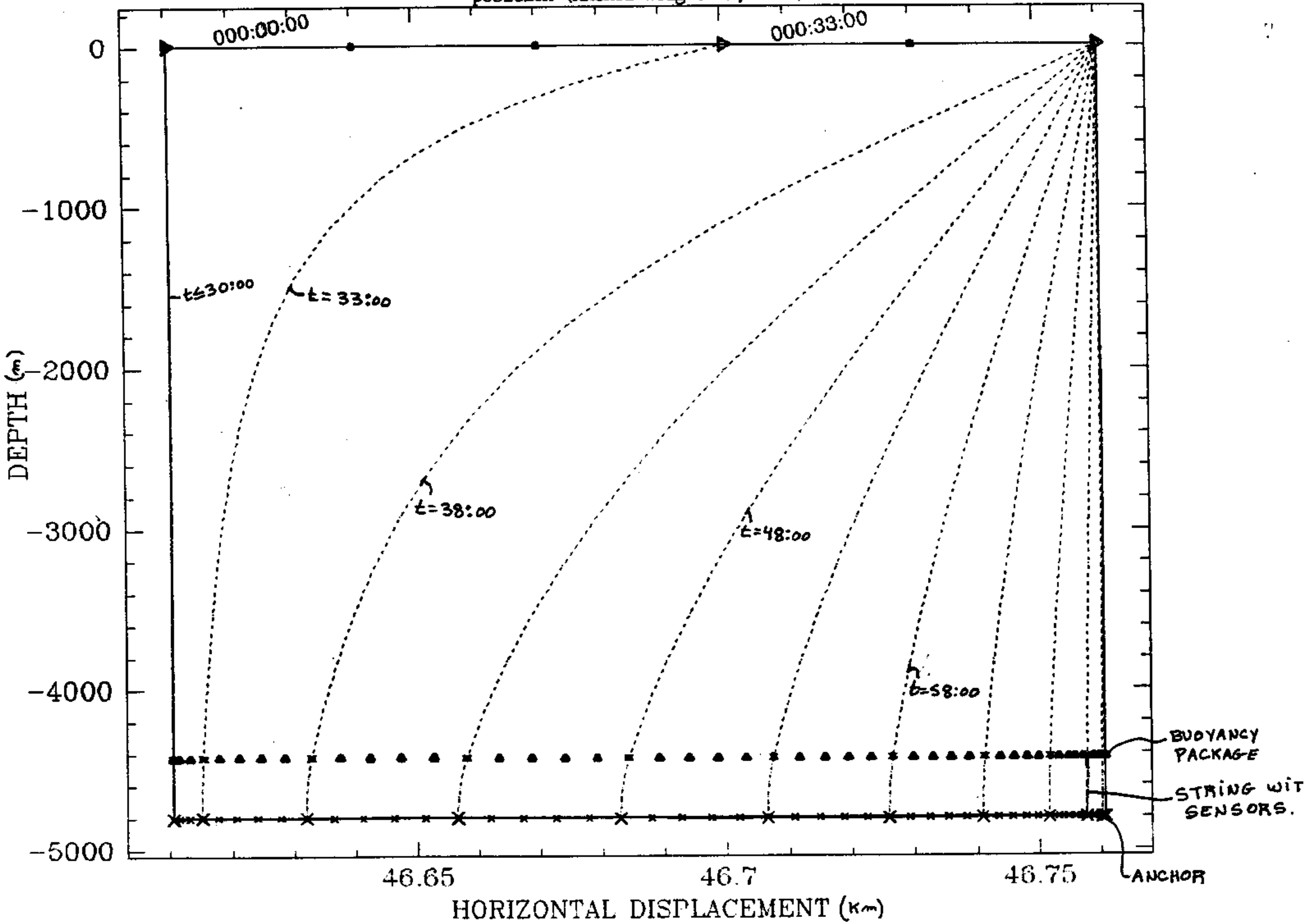


FIGURE 5. Run Test #2: System response to changes in ship position (Anchor weight = 9,500 N)

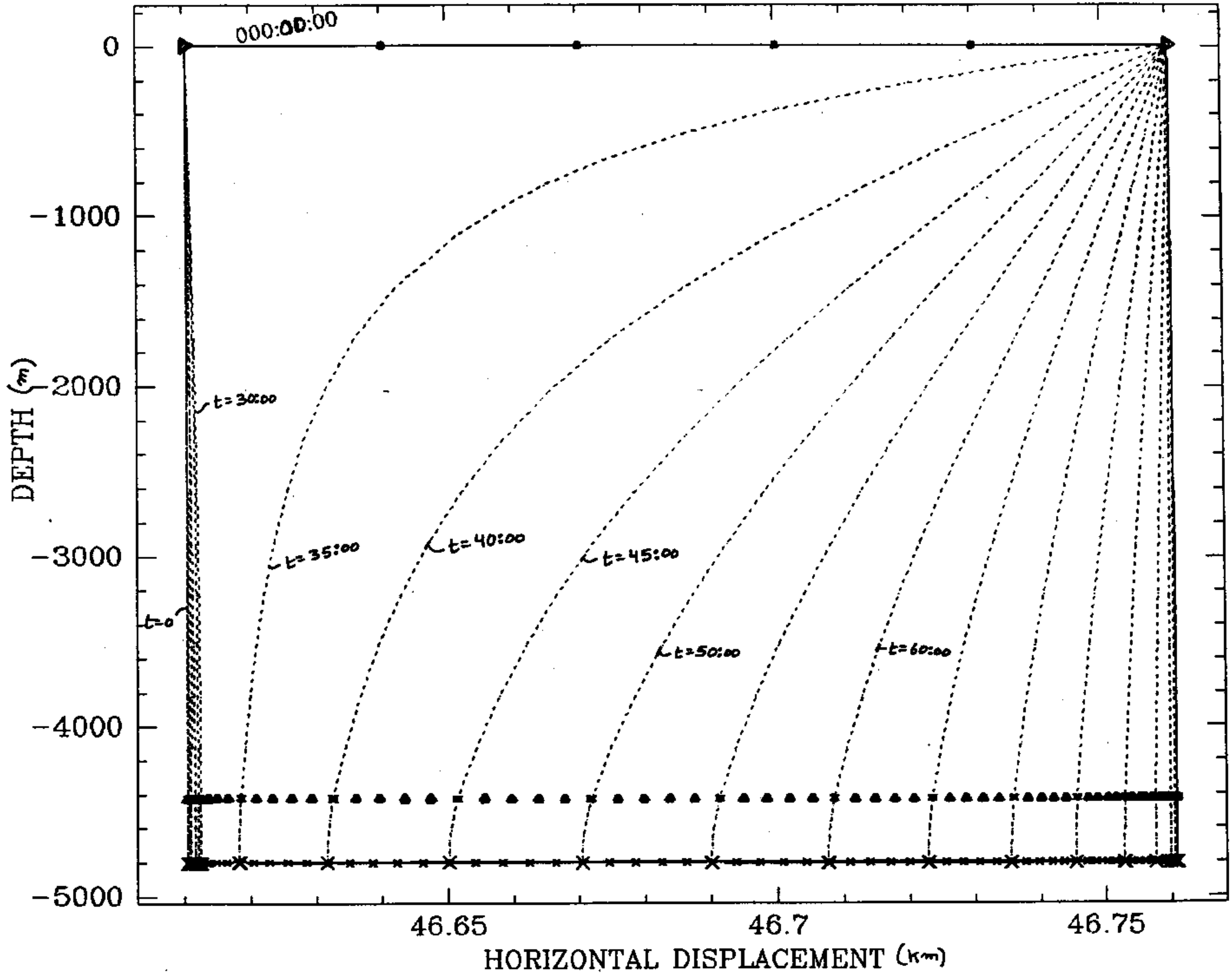
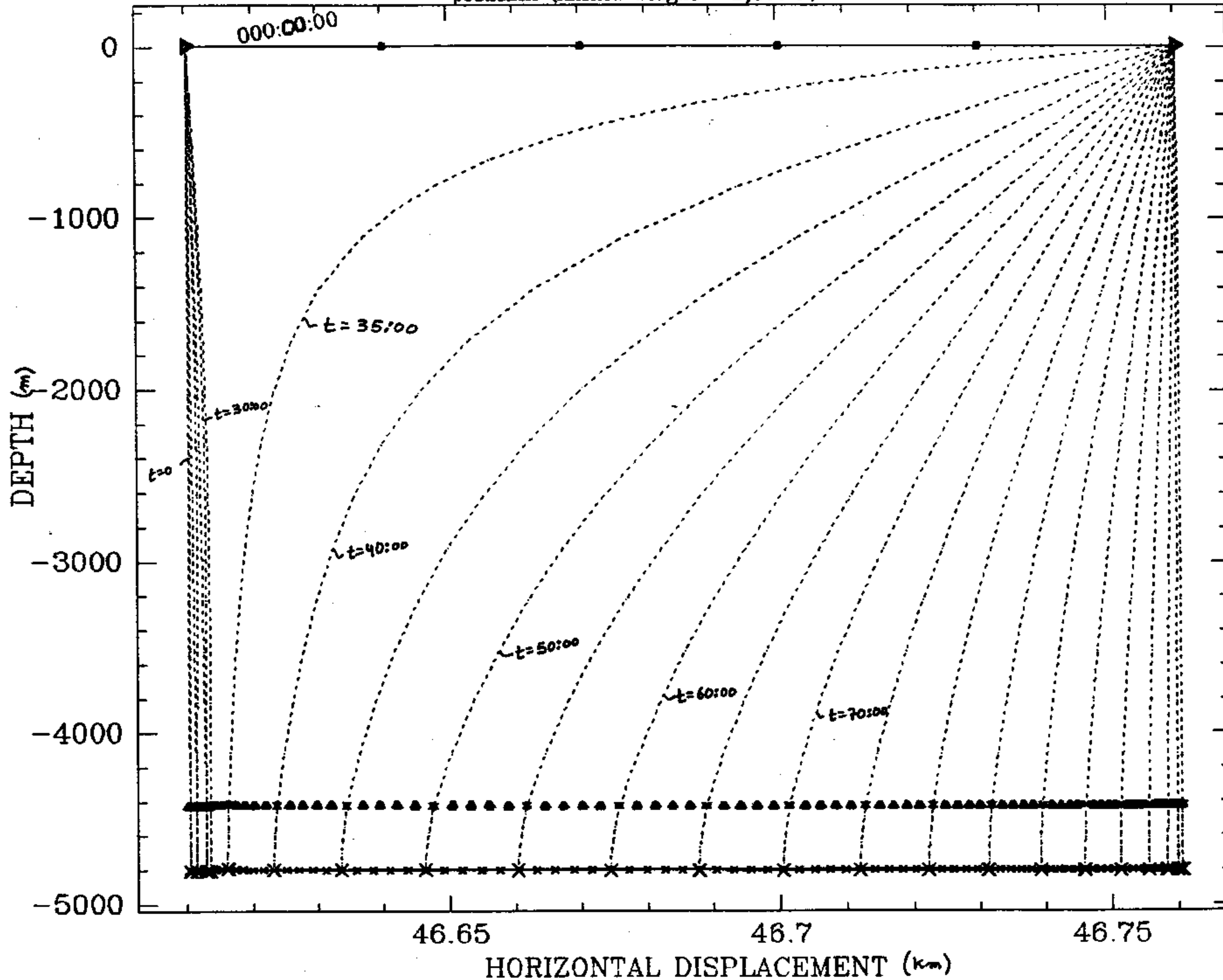


FIGURE 6. Run Test #3: System response to changes in ship position (Anchor weight = 2,500 N)

Tue Oct 15 13:34:29 1991



ANCHOR RESPONSE TO A TIME VARYING CURRENT

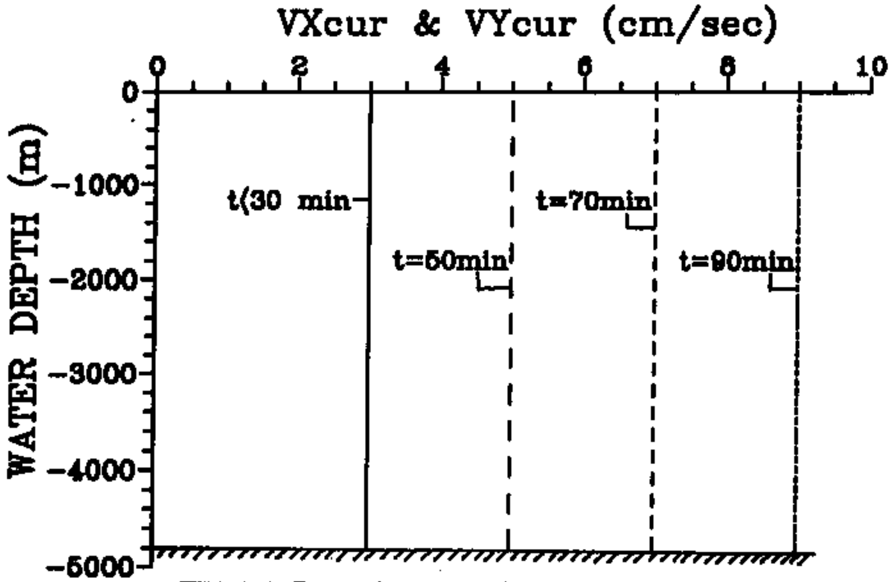


FIGURE 7. Time varying current acting on the cable.

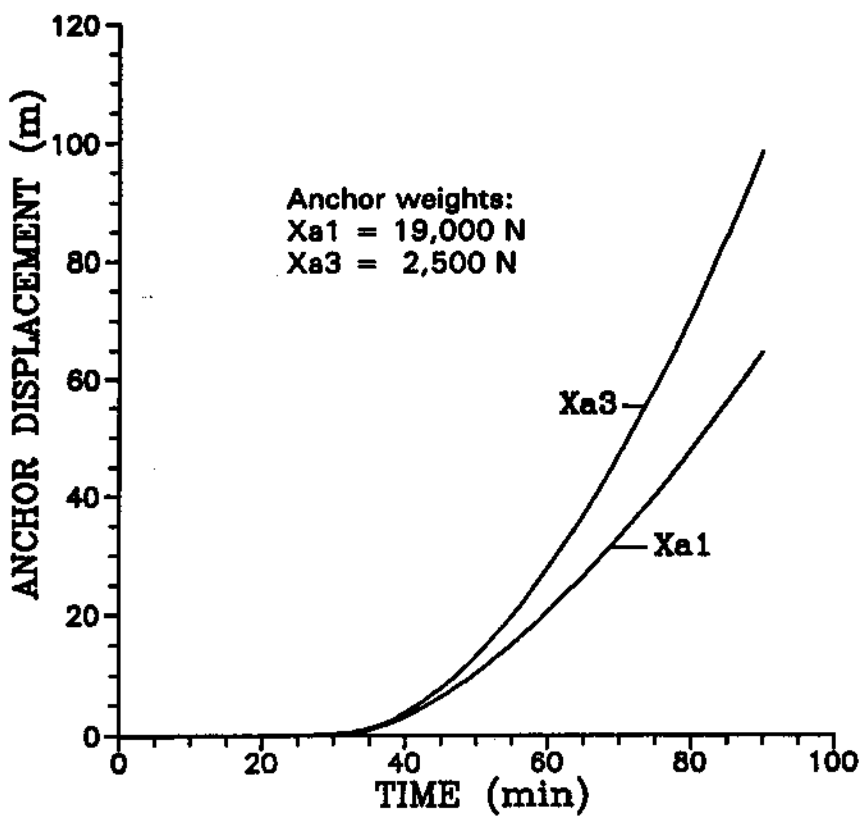


FIGURE 8. Anchor response to a time varying current.

FIGURE 9. System response to a time varying current.
(anchor weight = 19,000 N)

Wed Oct 23 12:57:11 1991

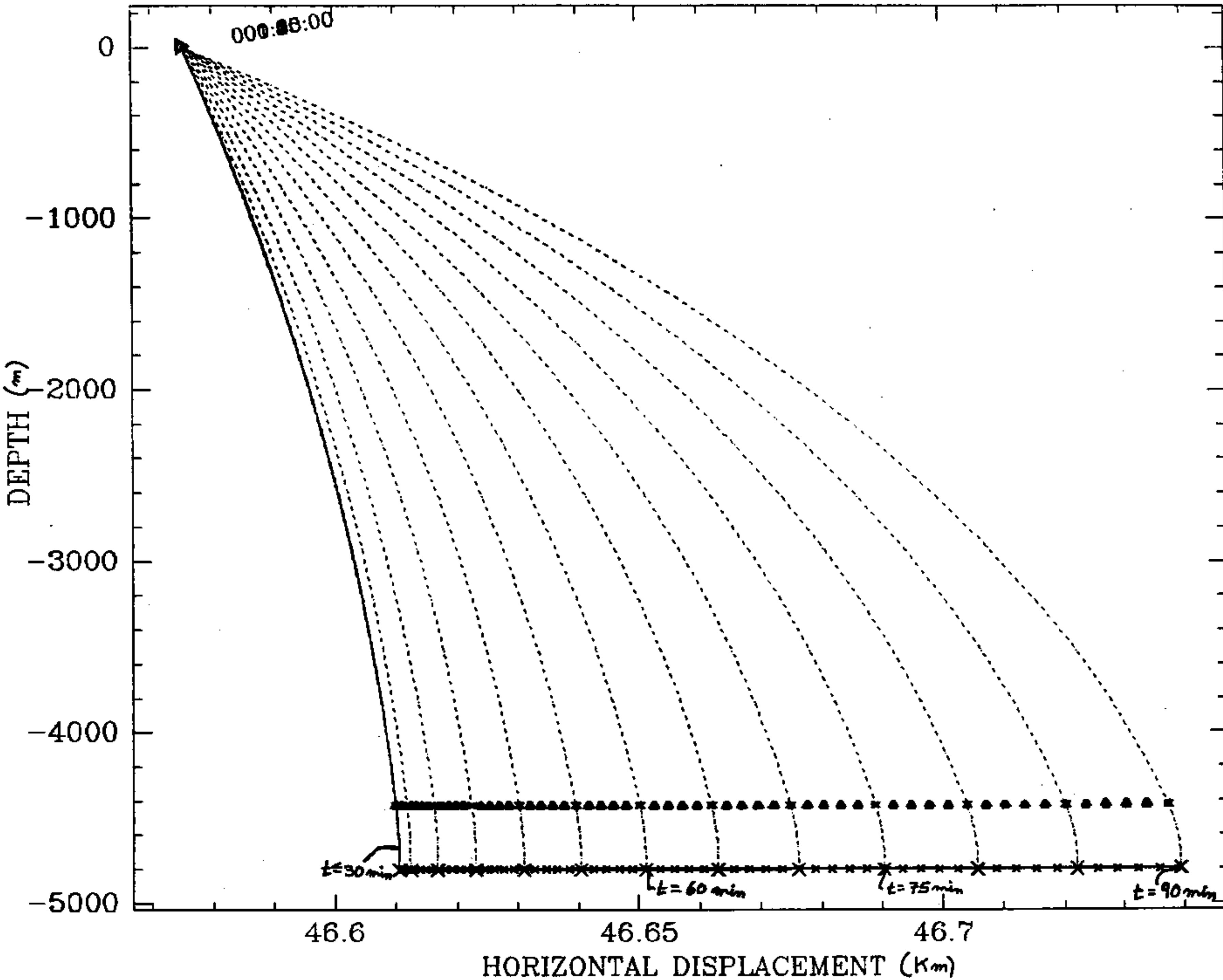
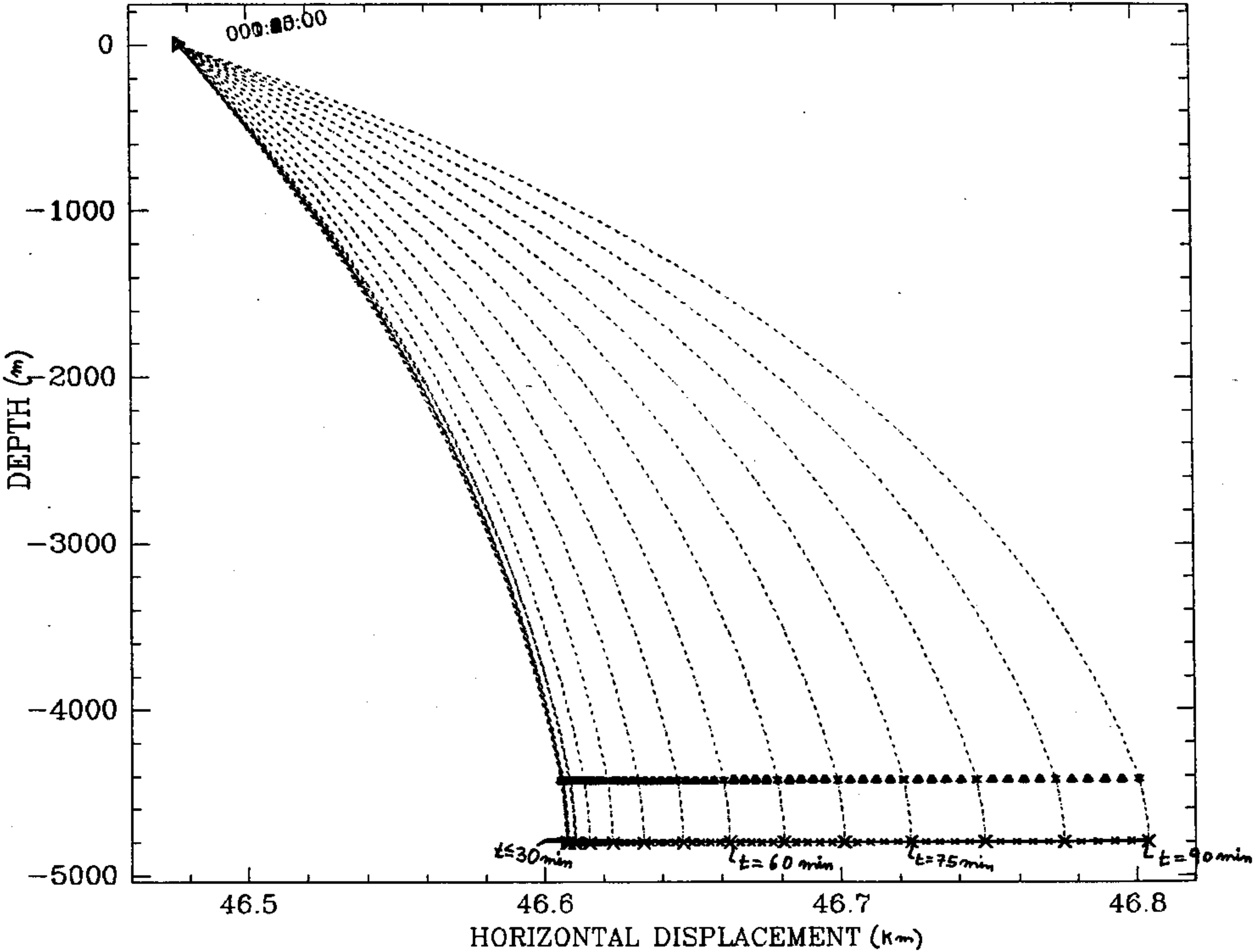


FIGURE 10. System response to a time varying current.
(anchor weight = 2,500 N)

Wed Oct 23 13:12:45 1991



EFFECT OF CURRENT PULSE ON ANCHOR
(steady state solution)

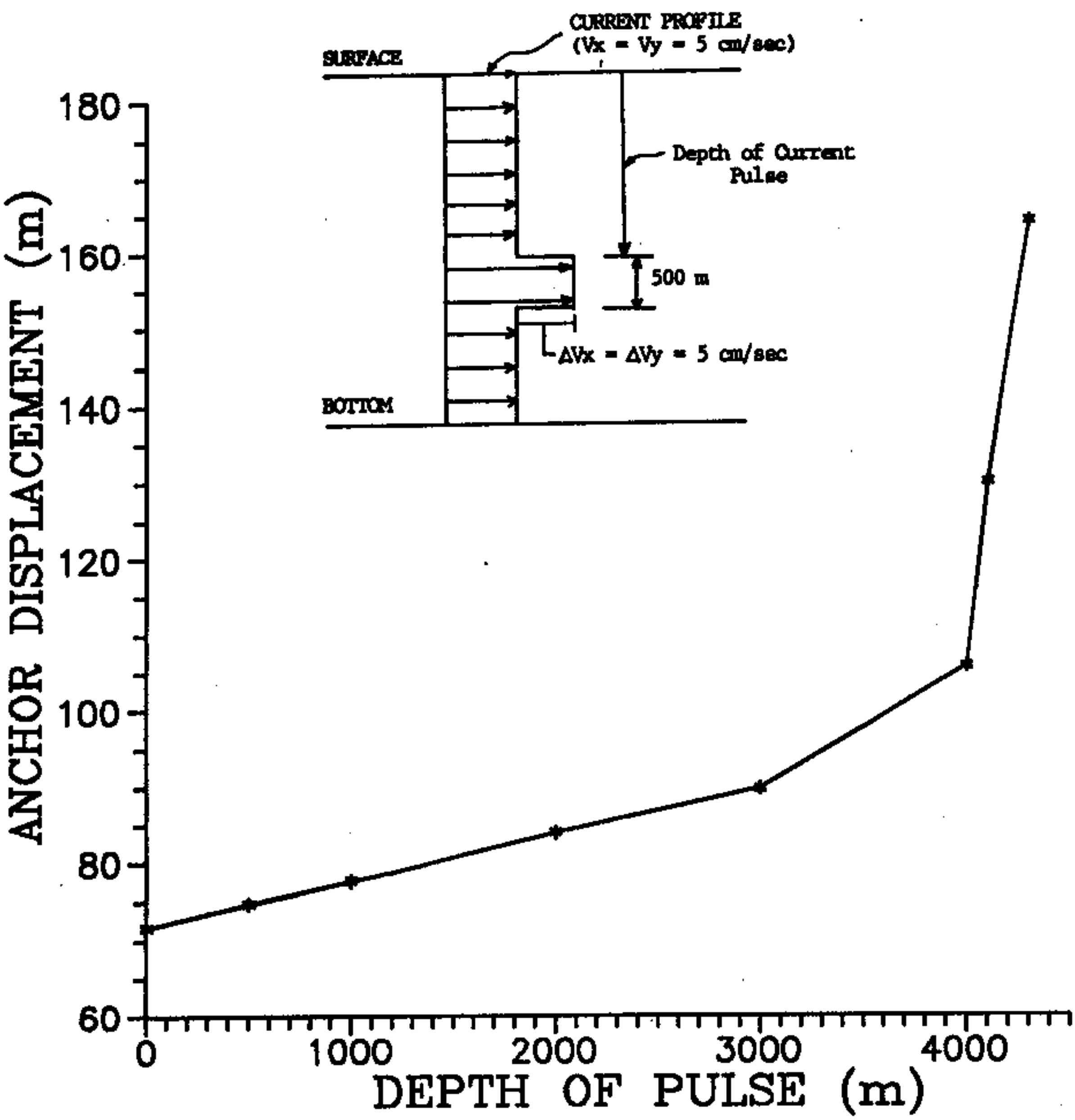


FIGURE 11. Effect of a current pulse on the anchor position (anchor weight = 19,000 N)

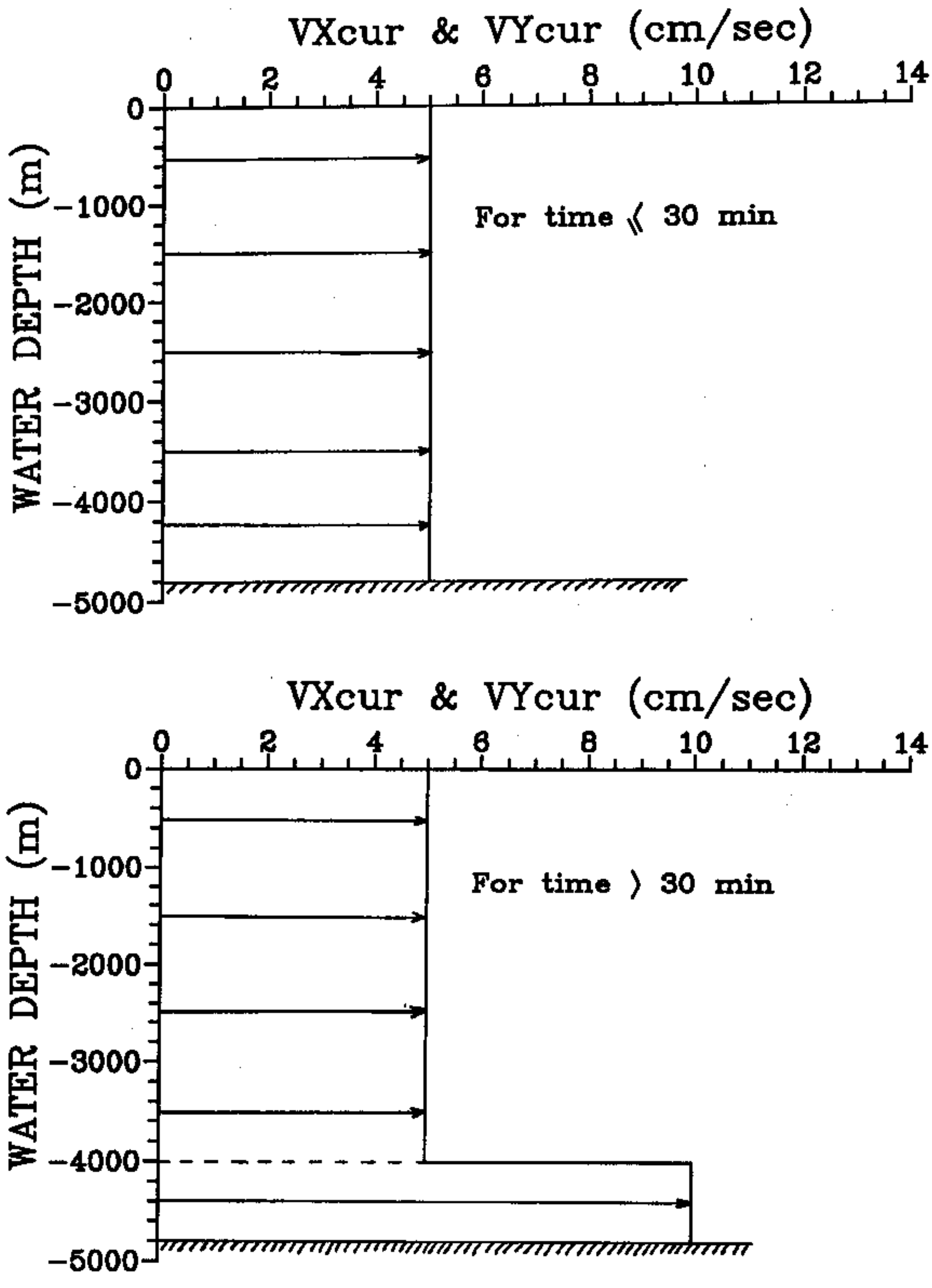


FIGURE 12. Current acting on the cable-string system.

FIGURE 13. System response to a change in bottom currents.
(anchor weight = 19,000 N)

Tue Oct 15 14:12:59 1991

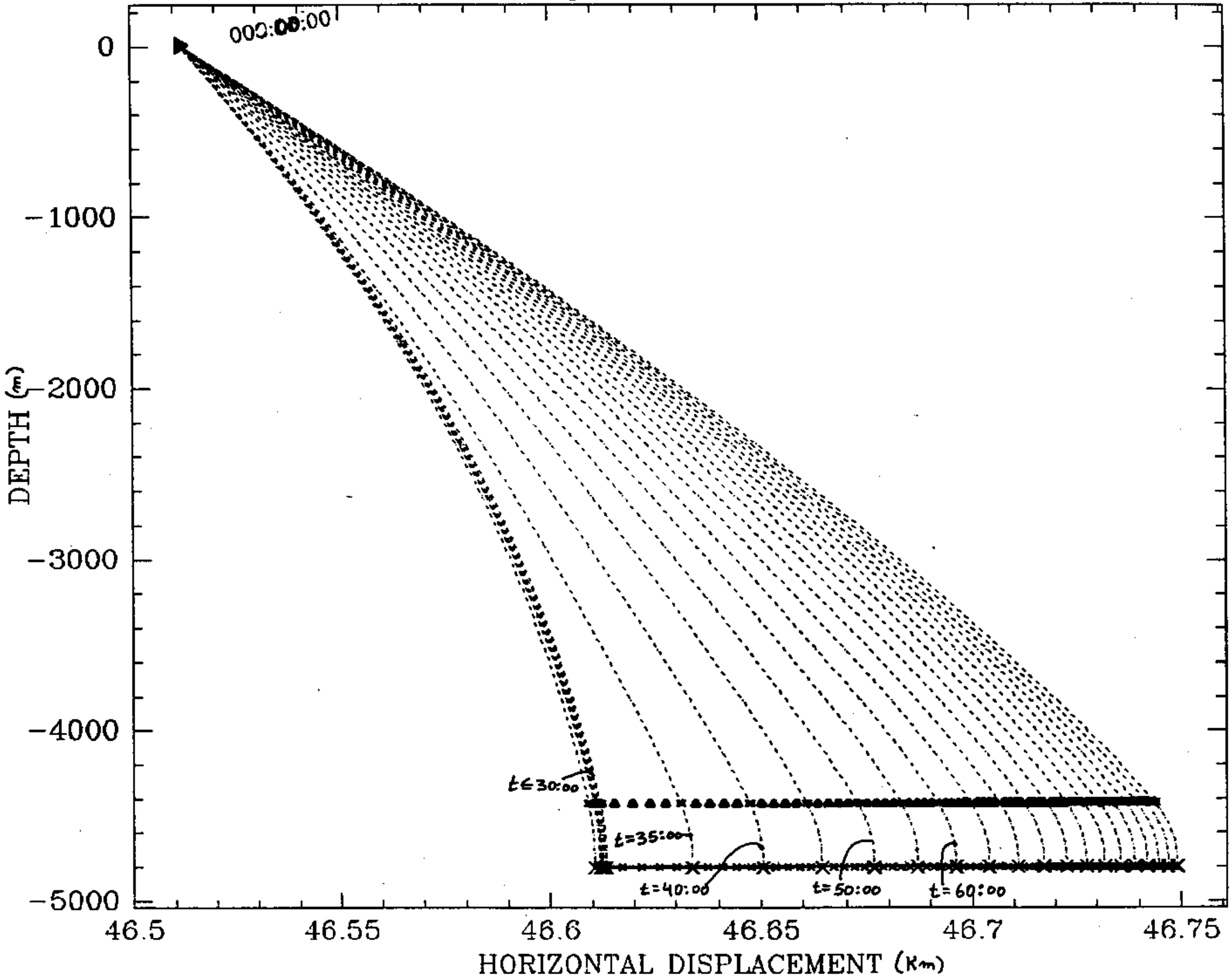


FIGURE 14. System response to a change in bottom currents
(anchor weight = 2,500 N)

Tue Oct 15 15:39:29 1991

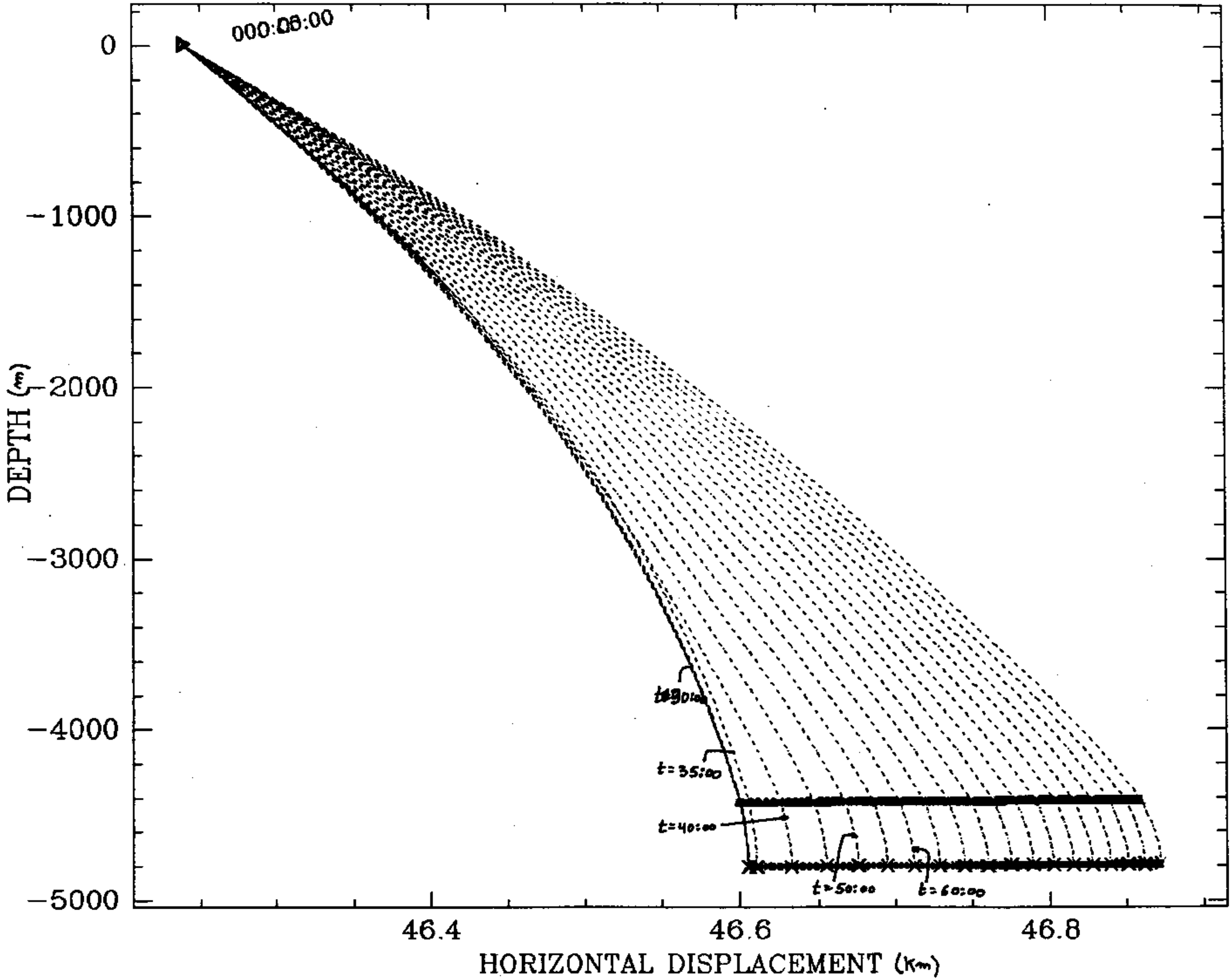


FIGURE 15. System response to changes in bottom current.
(anchor weight=19,000 N, using 1/2" wire rope)

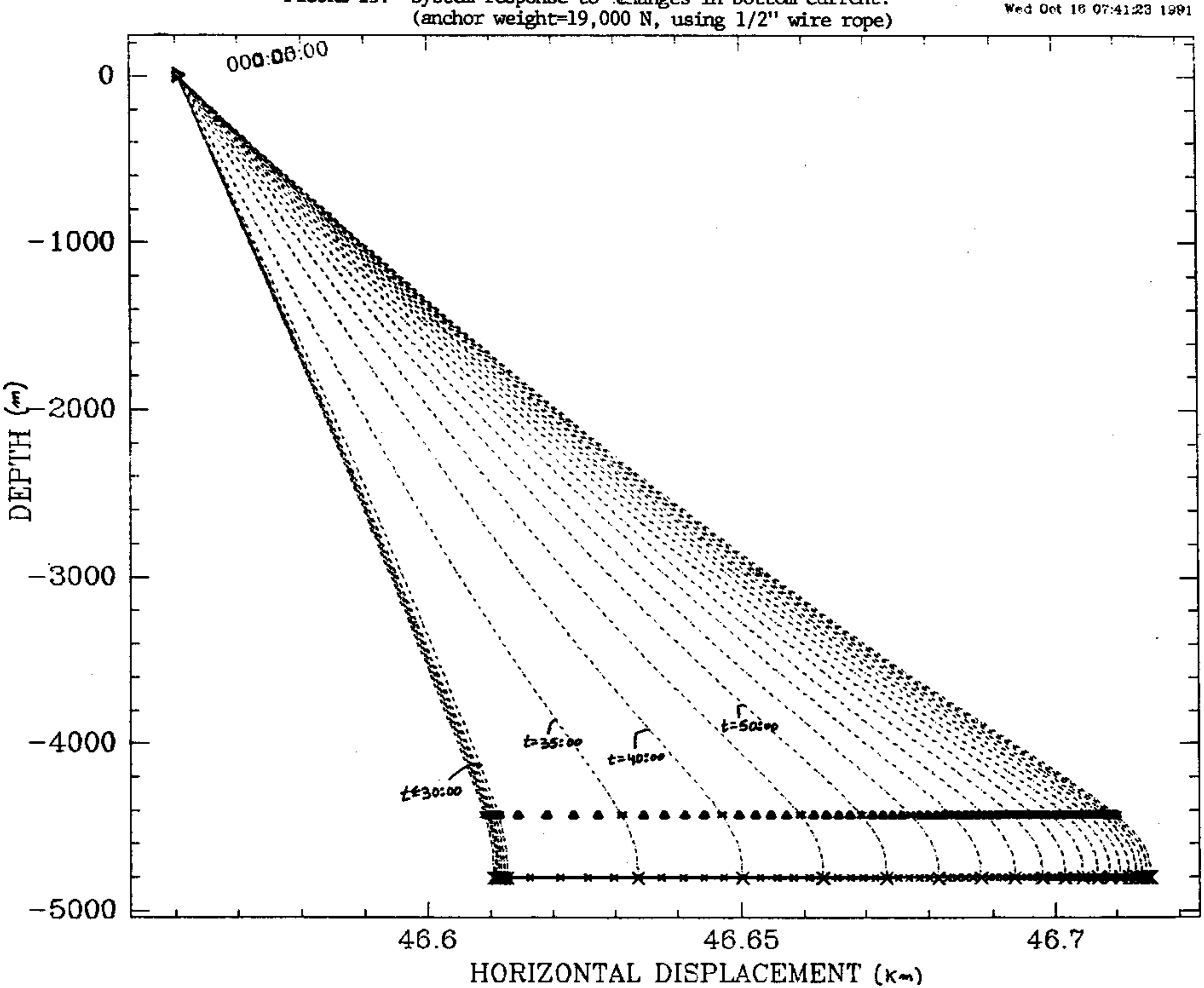
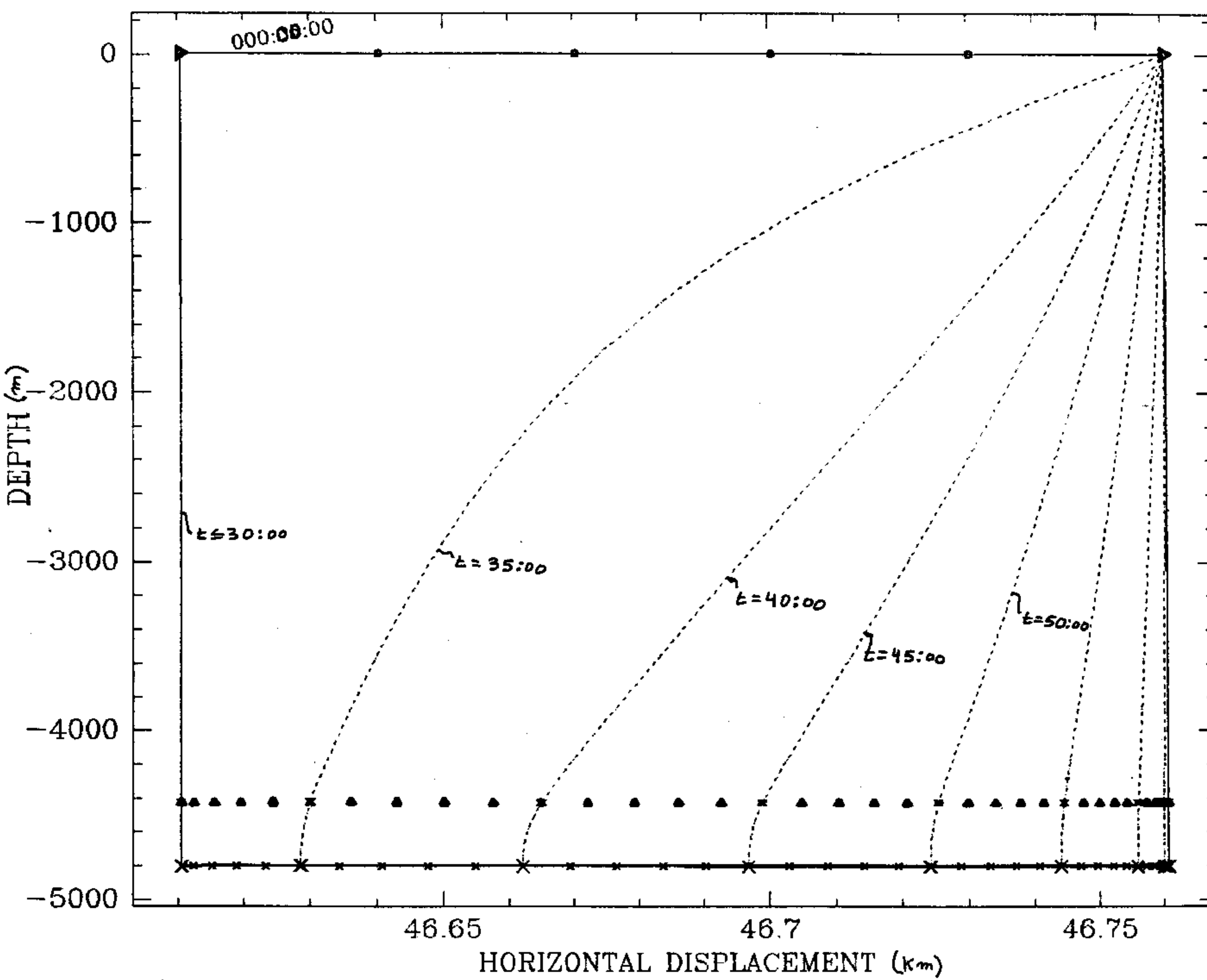


FIGURE 16. System response to changes in ship position. (using 1/2" wire rope to lower string).



ANCHOR RESPONSE TO CHANGES IN SHIP POSITION

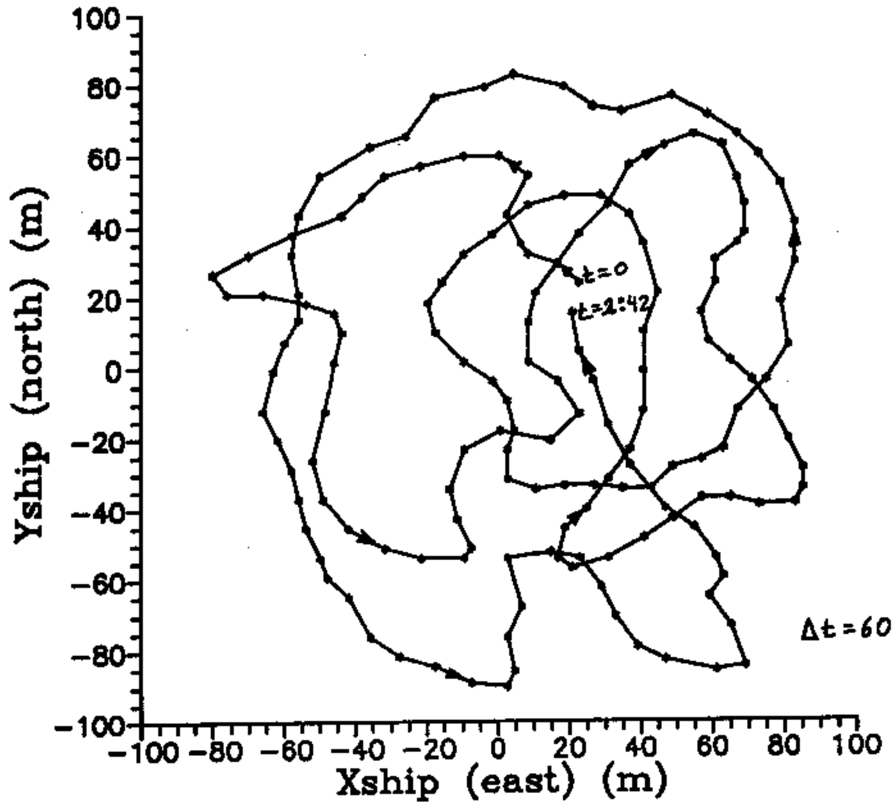


FIGURE 17

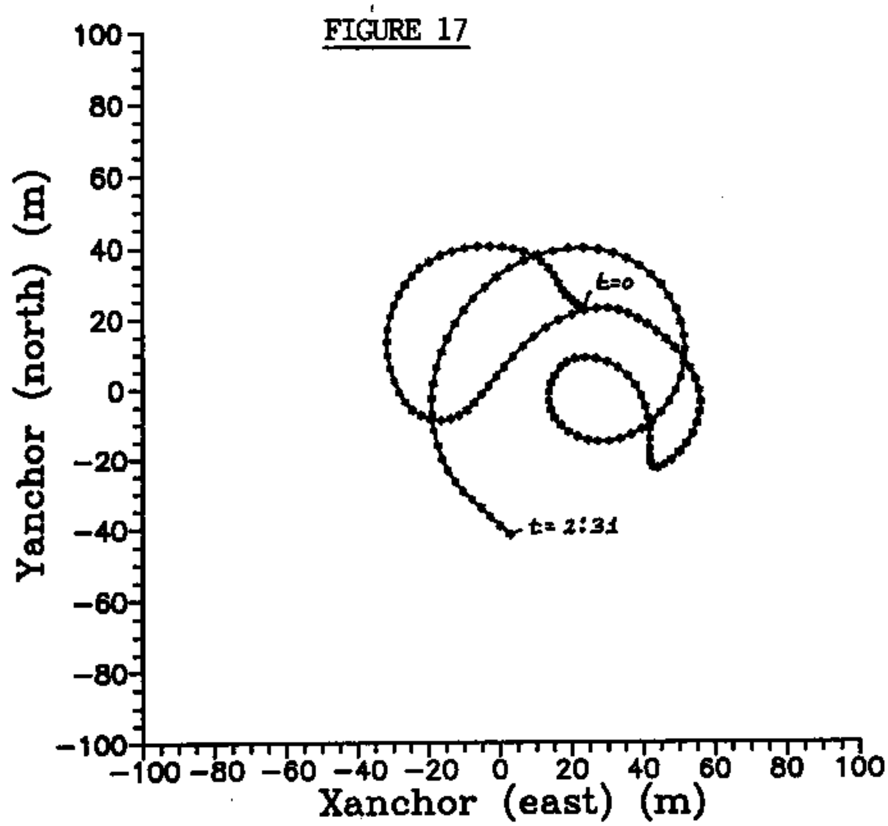


FIGURE 18.

ANCHOR RESPONSE TO CHANGES IN SHIP POSITION

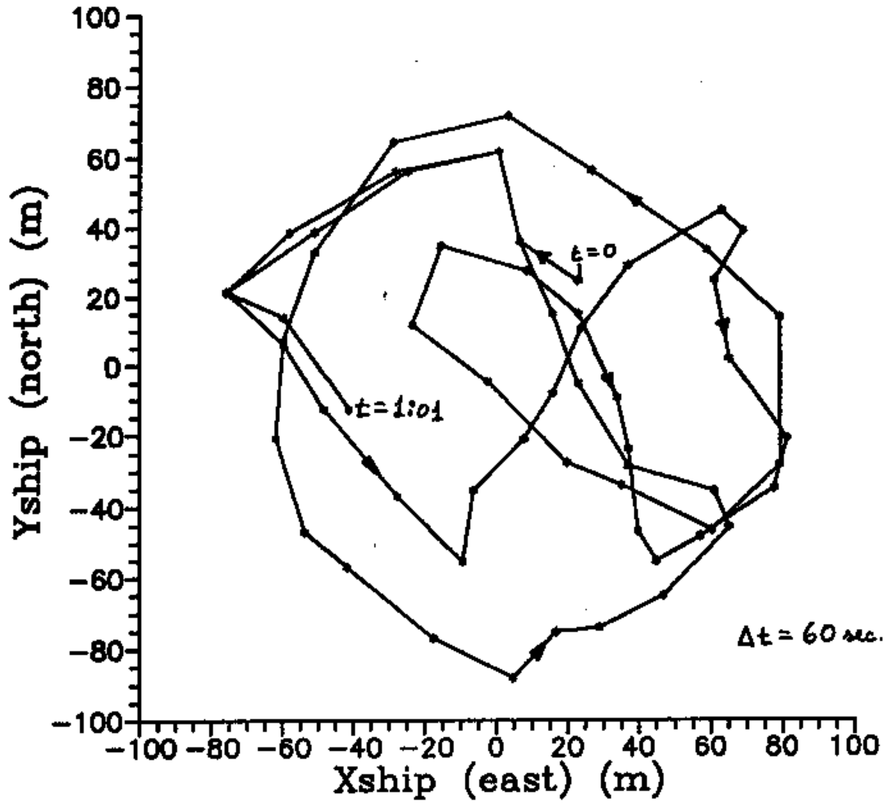


FIGURE 19.

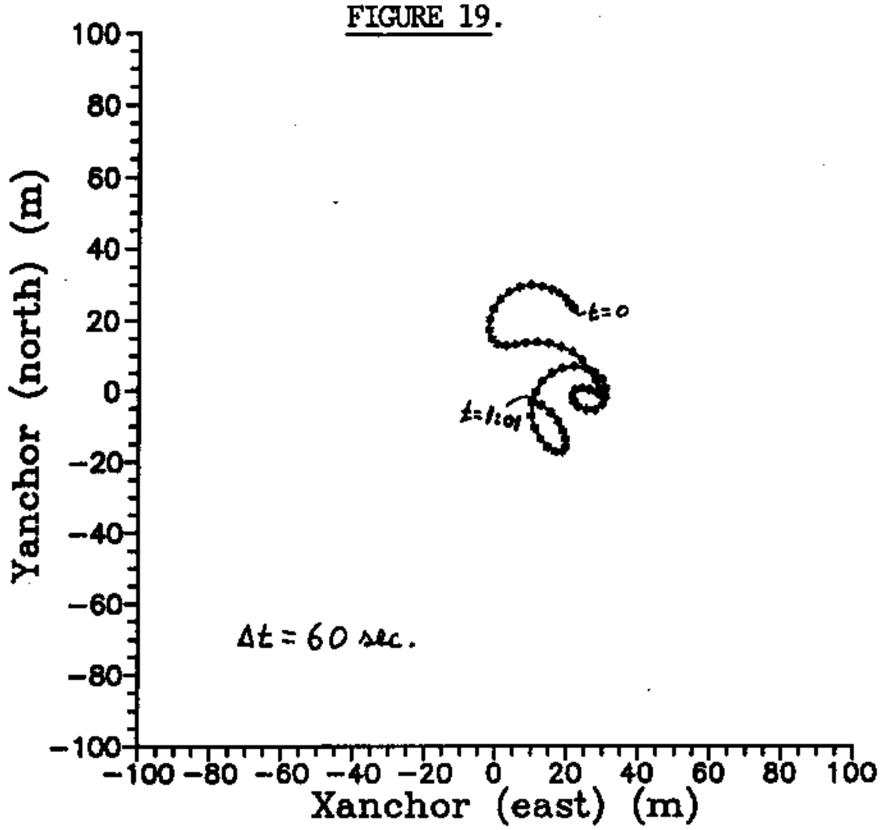


FIGURE 20.

ANCHOR RESPONSE TO CHANGES IN SHIP POSITION

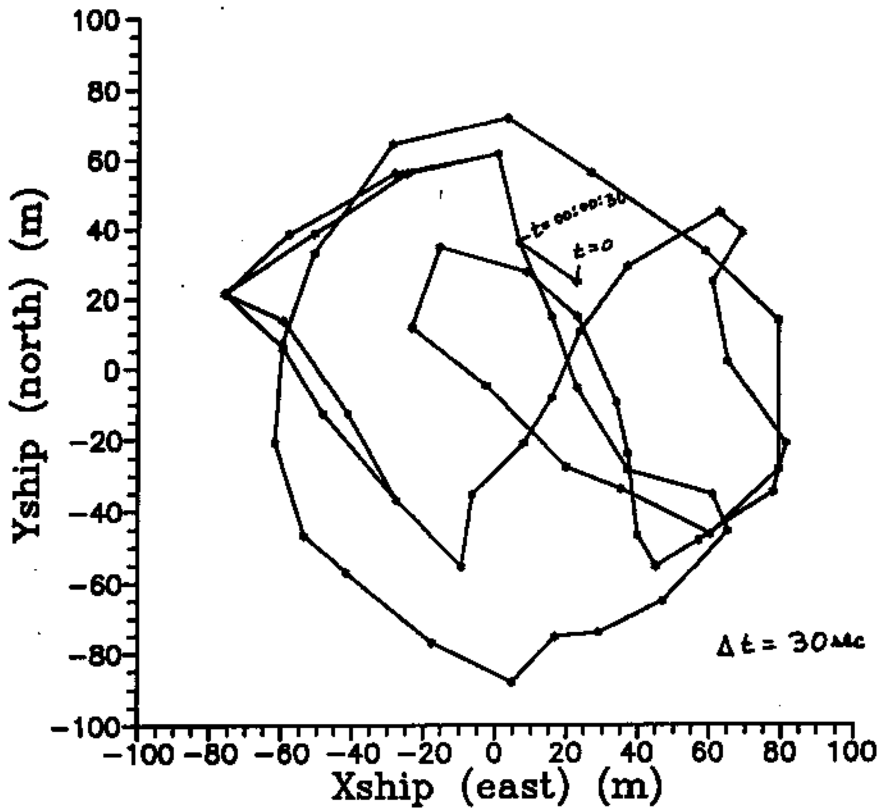


FIGURE 21.

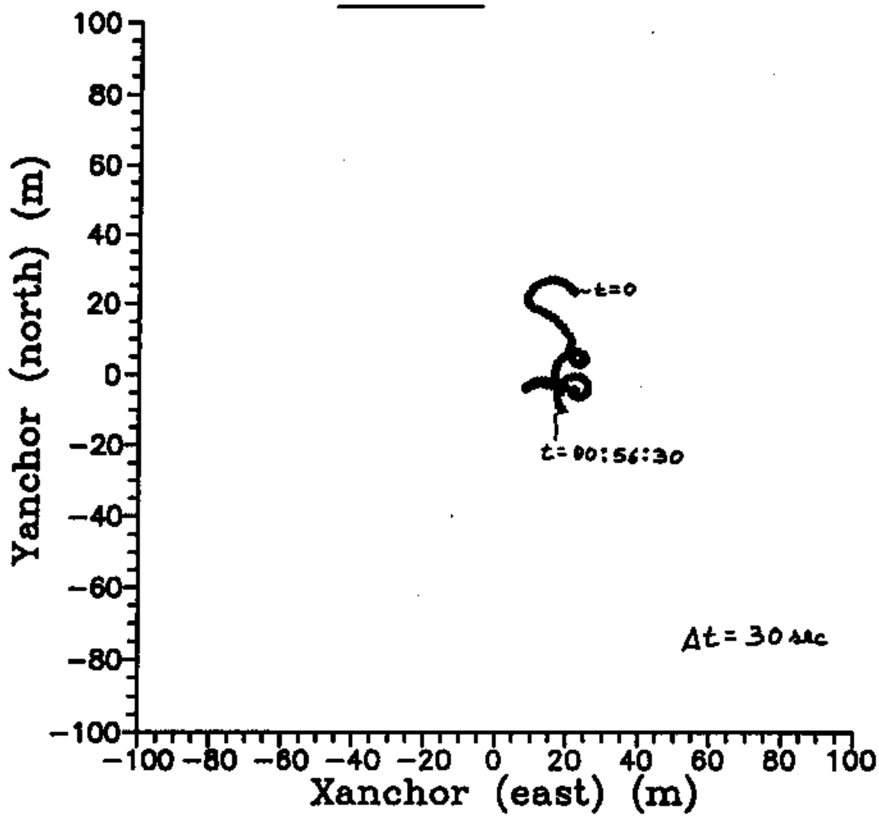


FIGURE 22.

ANCHOR RESPONSE TO CHANGES IN SHIP POSITION

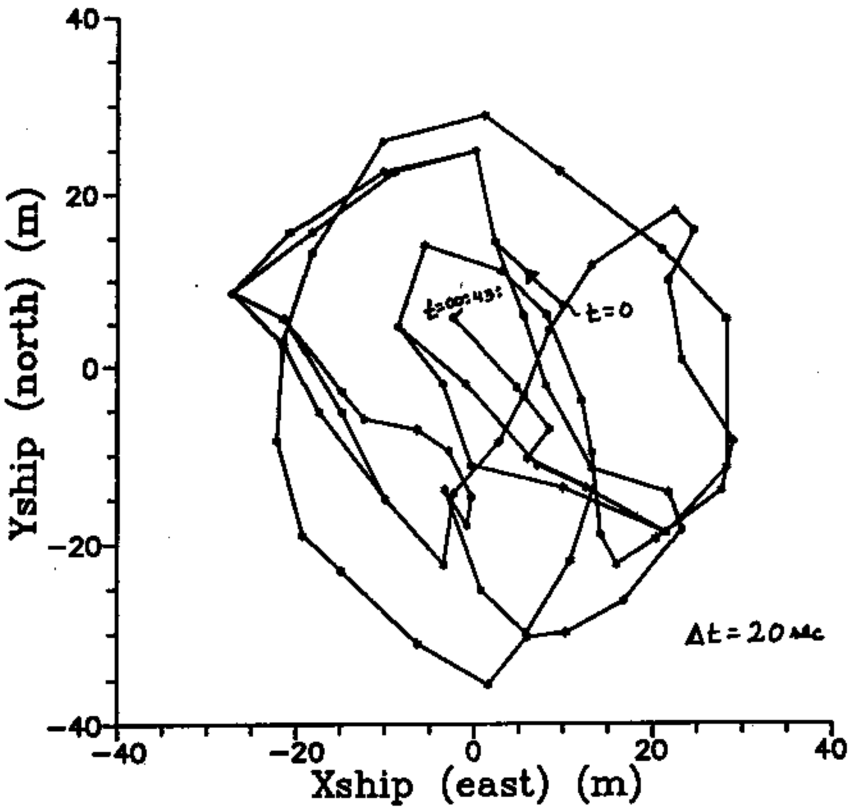


FIGURE 23.

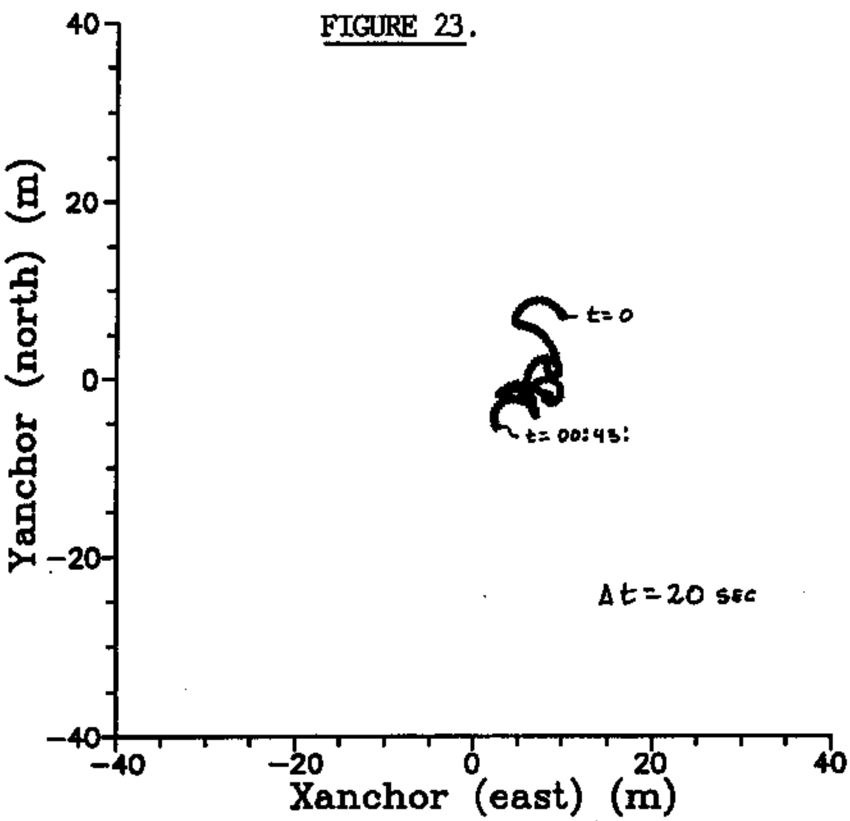


FIGURE 24.

ANCHOR RESPONSE TO CHANGES IN SHIP POSITION

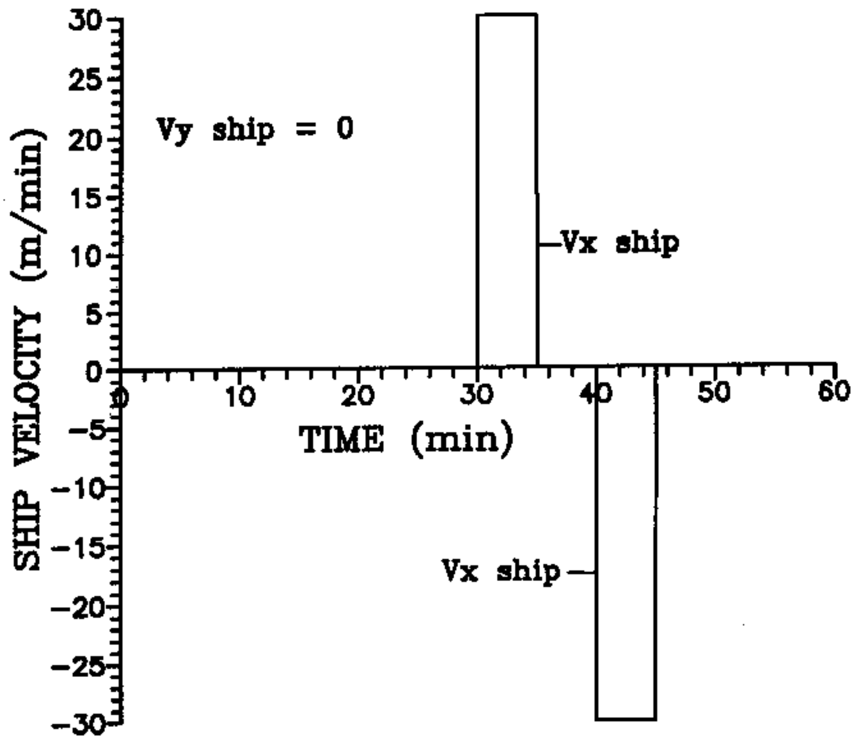


FIGURE 25

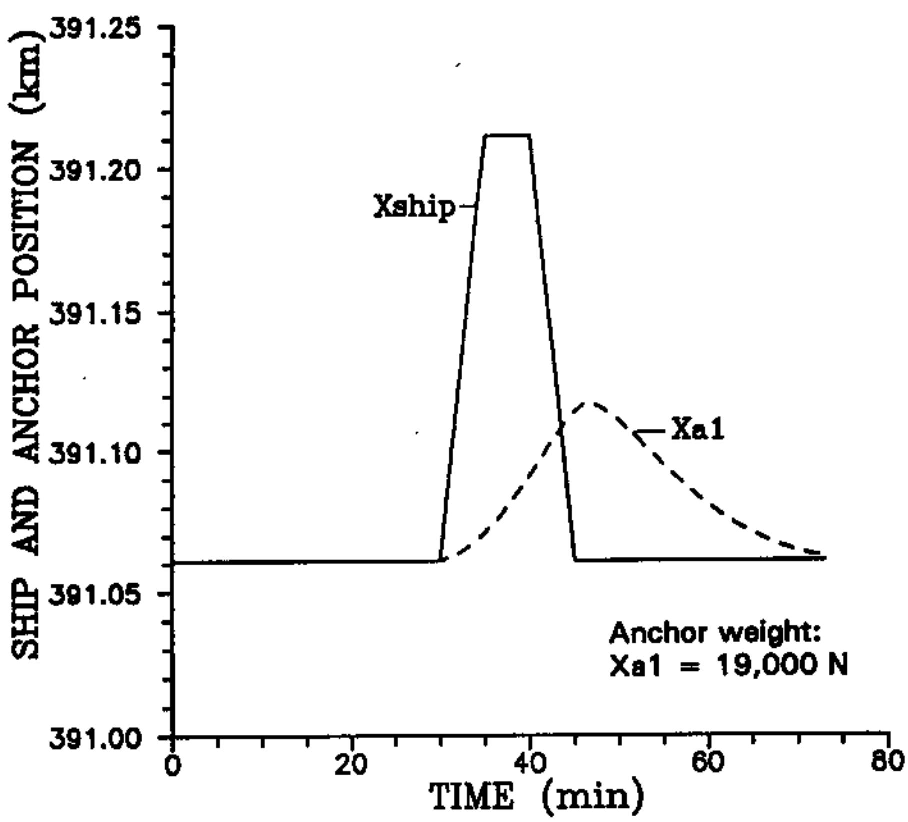
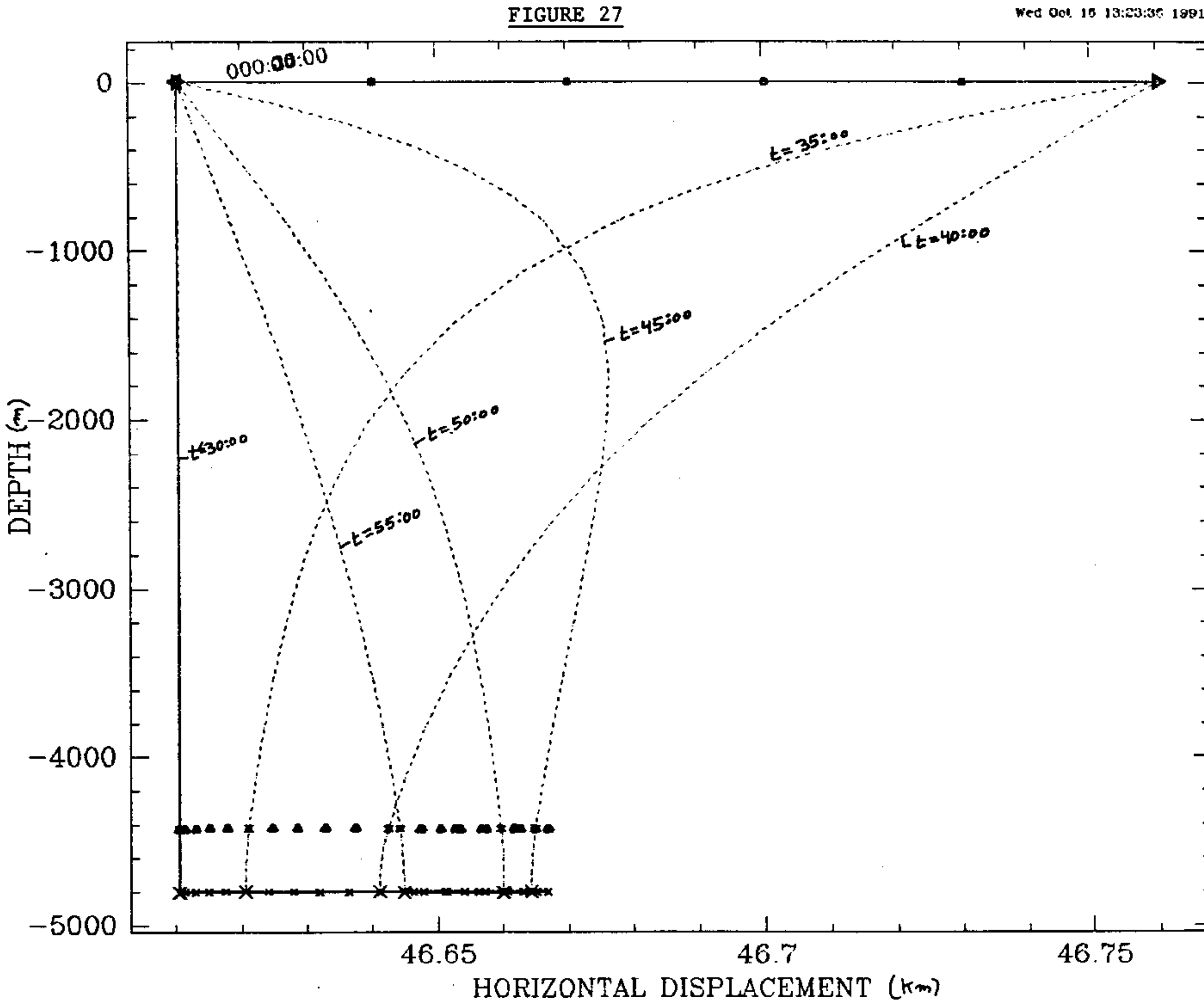


FIGURE 26

FIGURE 27


Wed Oct 16 13:23:35 1991
000:00:00
t=35:00
t=40:00
t=45:00
t=50:00
t=55:00
t=30:00
0
-1000
-2000
-3000
-4000
-5000
DEPTH (m)
46.65
46.7
46.75
HORIZONTAL DISPLACEMENT (km)

ANCHOR RESPONSE TO CHANGES IN SHIP POSITION

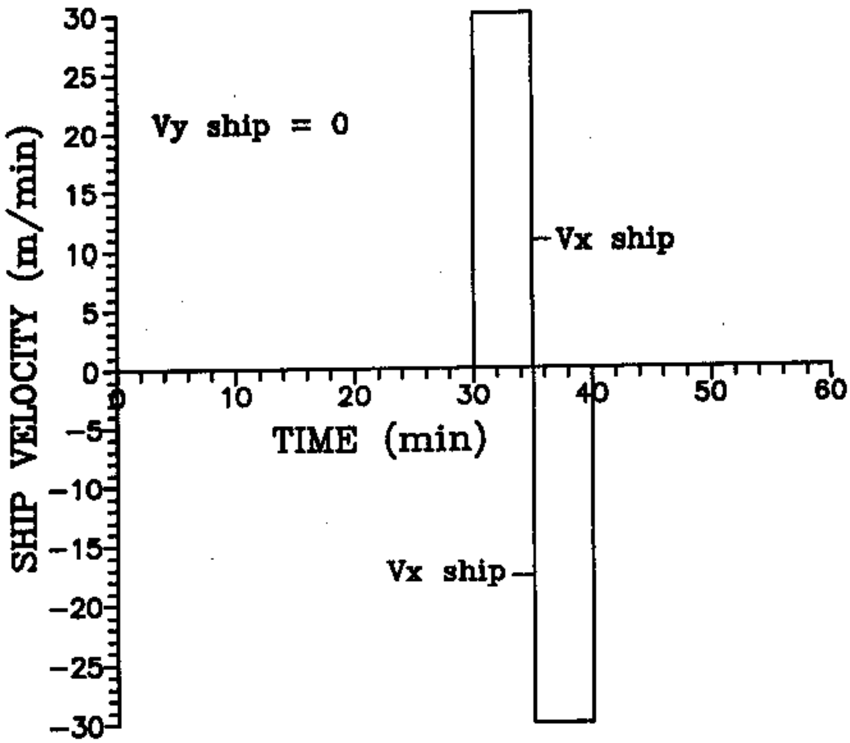


FIGURE 28

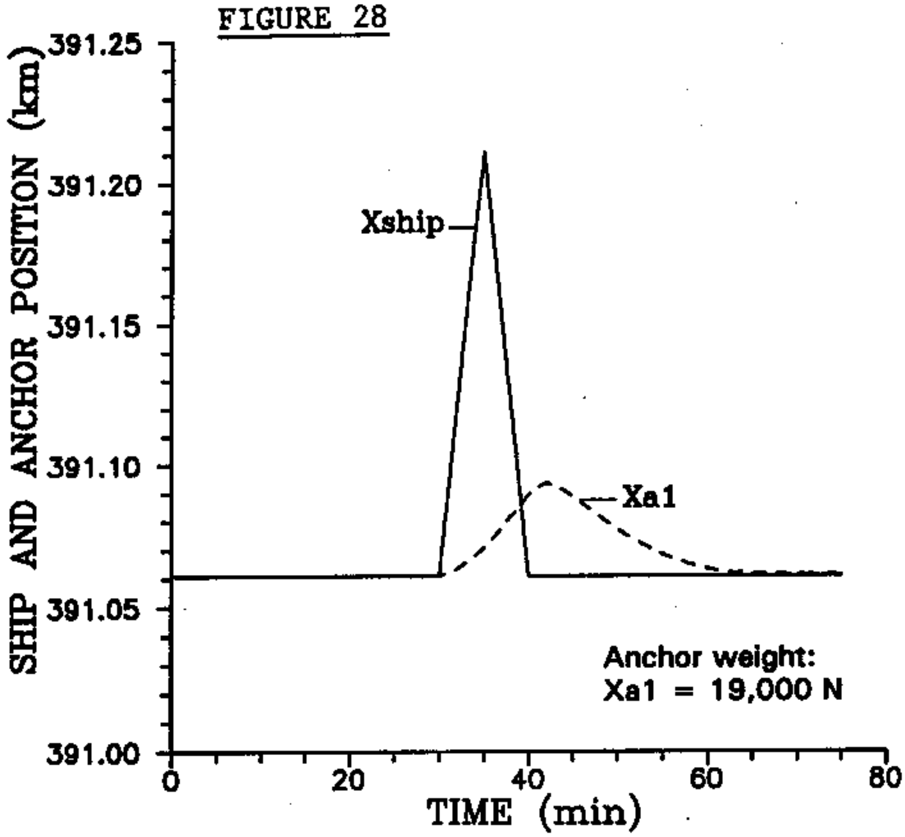
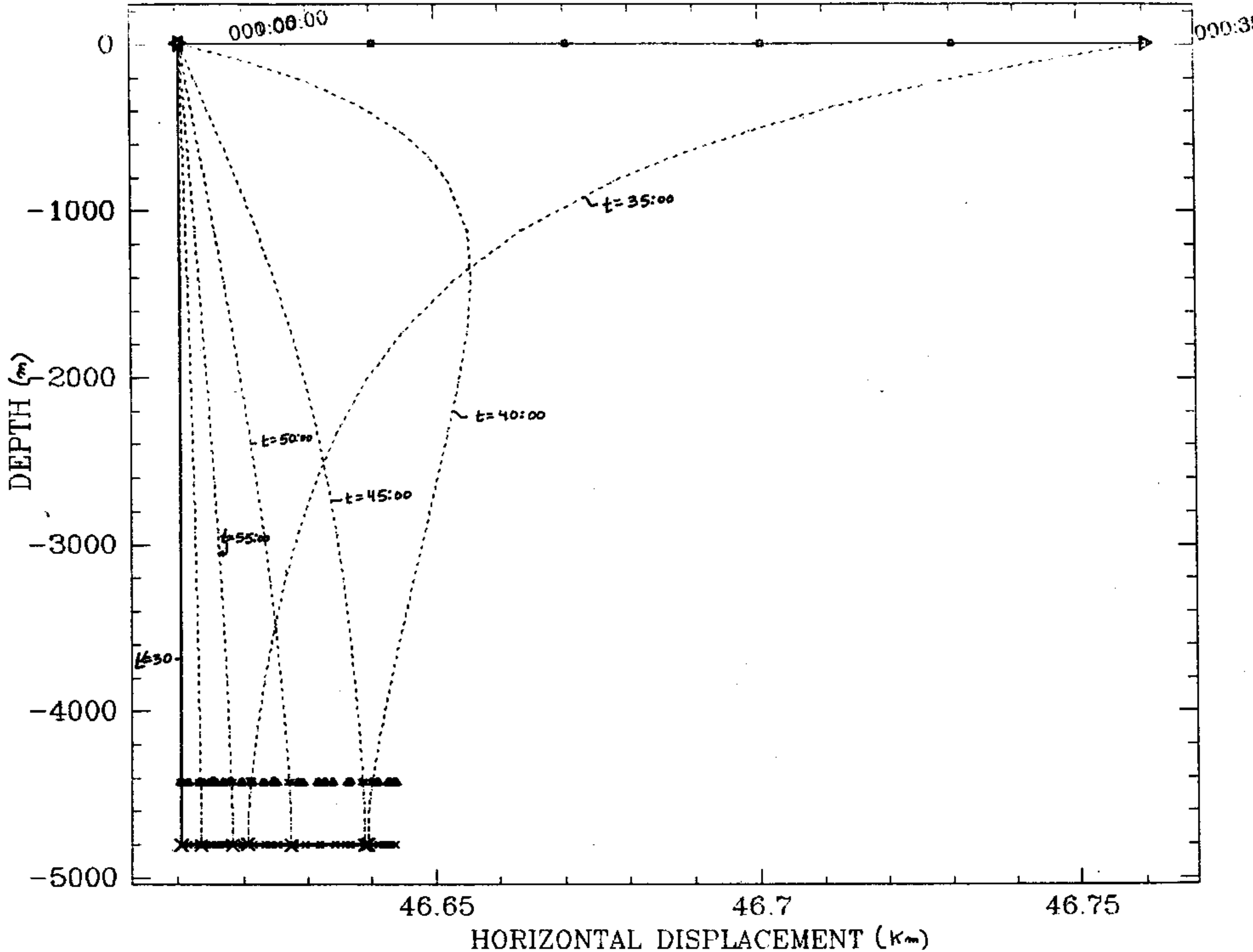


FIGURE 29

FIGURE 30

Thu Oct 24 13:22:35 1991



ANCHOR RESPONSE TO CHANGES IN SHIP POSITION

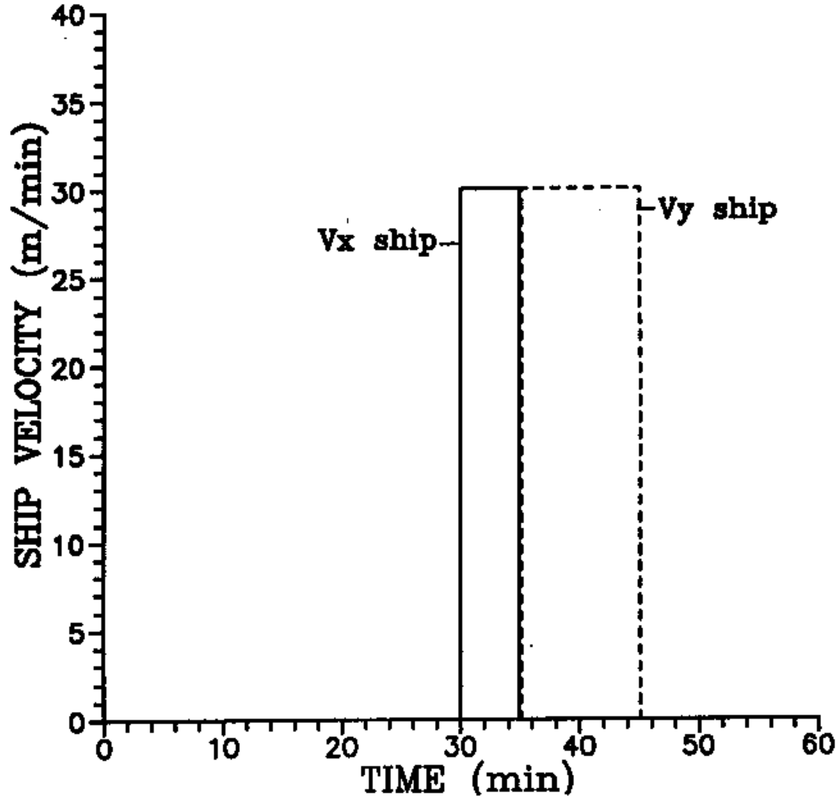


FIGURE 31

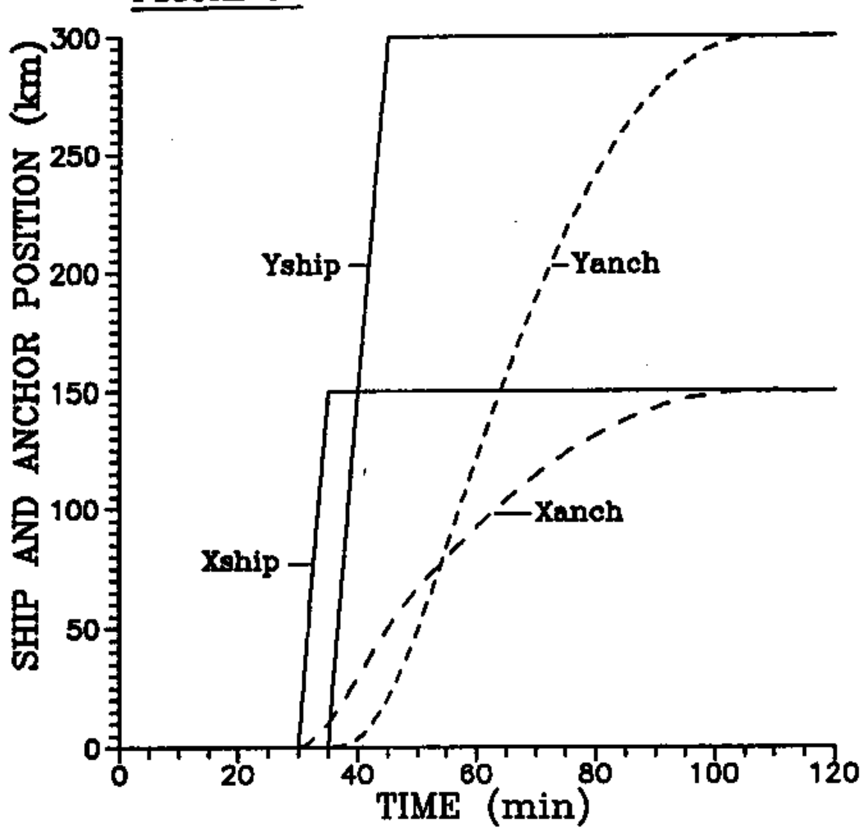
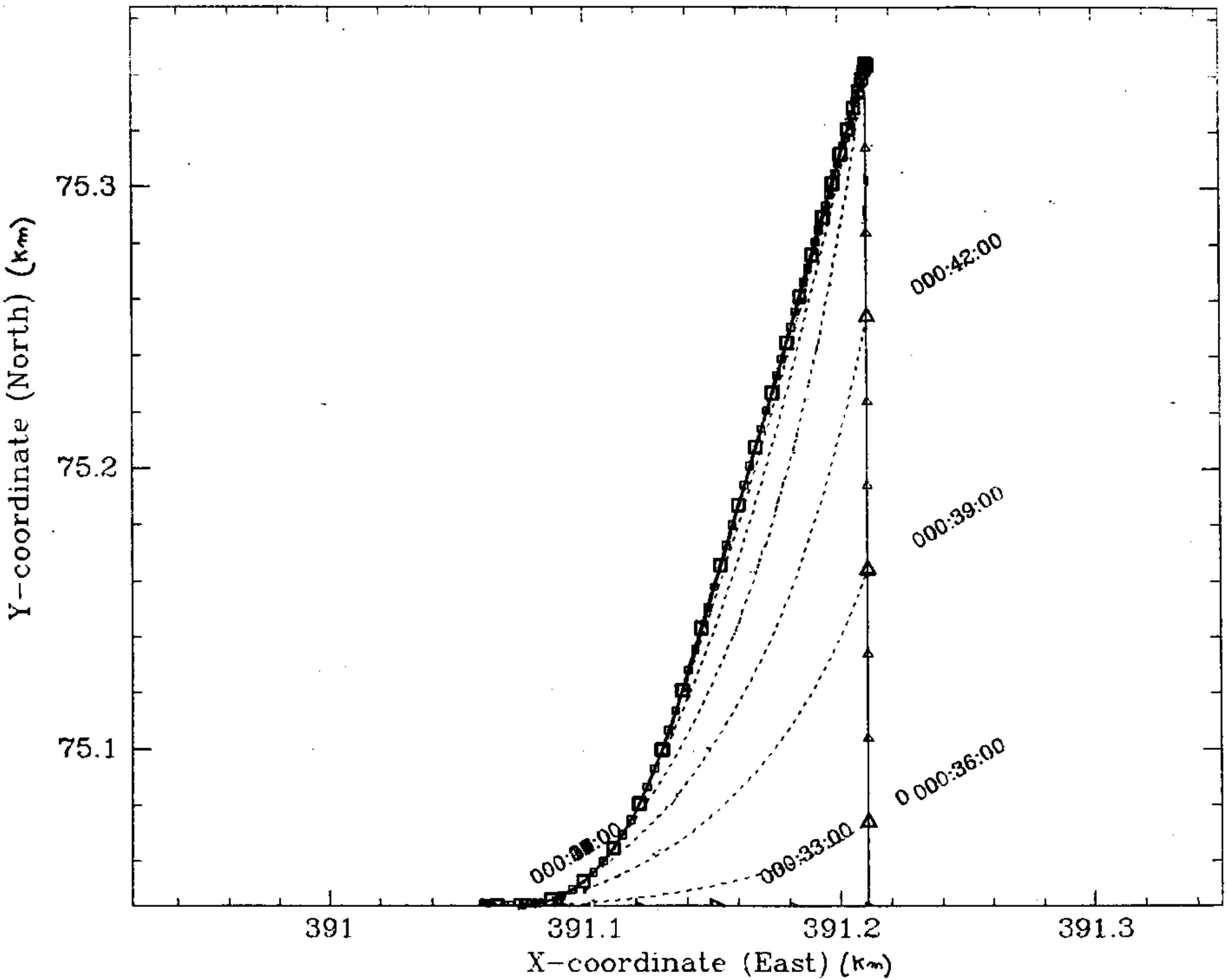


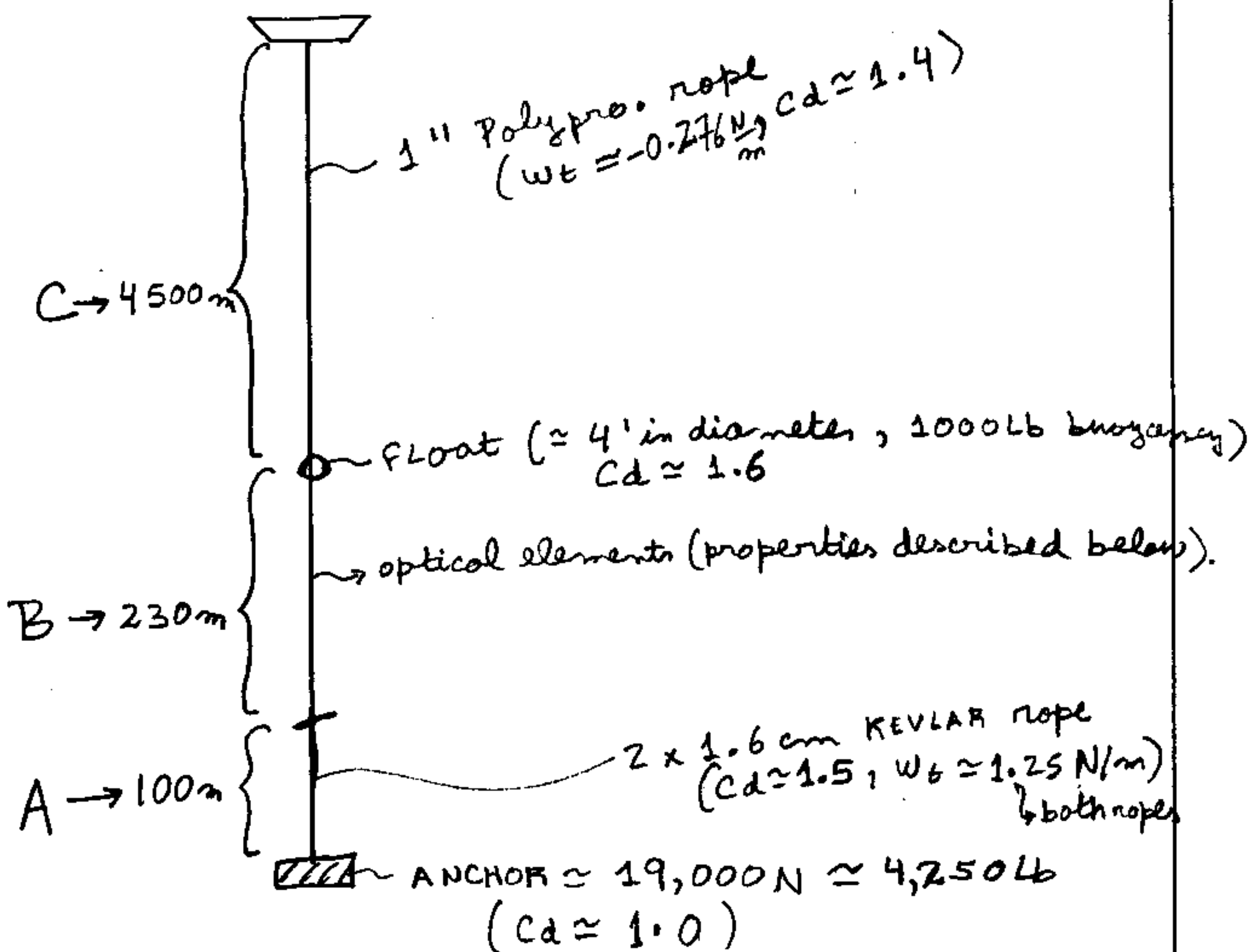
FIGURE 32

FIGURE 33

Mon Oct 21 13:30:39 1991



BASIC CONFIGURATION:



KEVLAR rope (5/8") ; dry weight ≃ 14 Lb/100 ft, $\gamma = 1.44$
→ wet weight ≃ +0.625 N/m

POLYP. rope (1") ; dry weight ≃ 17 Lb/100 ft, $\gamma = 0.90$
→ wet weight ≃ -0.276 N/m

MAKAI OCEAN ENGINEERING, INC.
P.O. BOX 1206, KAILUA, OAHU, HAWAII 96734
TEL (808) 259-5940 FAX (808) 259-8238

DATE: OCT-91
PROJECT: DUMAND - STRING DEPLOY.
BY: JA

ELEMENTS IN STRING (B):

TOTAL wet weight (Newtons) = −130 −10 + 220 + 1320 + 5×(220) + 220 −10 + 880 + 3(220) − 300 + 220 + 1(220) + 220 + 220 + 1(220) + 220 − 10 + 1100 + 4(220) + 220 + 660 + 2(220) = 8560 N ≃ 1,922 Lb

wt/length ≃ 37.2 N/m

EQUIVALENT Shape for String → Total cross-sectional area:

(a) 30 × 0.457 × 1.3 = 17.8 m²

- 0.457 → benthos sphere
- 1.3 → factor to account for frame + cable + miscellaneous.

(b) 12 m² → hydrophone + String controller + 2 cables (230 m long)

TOTAL AREA ≃ 29.8 m² ≃ 30 m²

EQUIV. STRING DIAMETER = $\frac{30}{230}$ m ≃ 13 cm

USE $C_D \simeq 1.6$ for String.

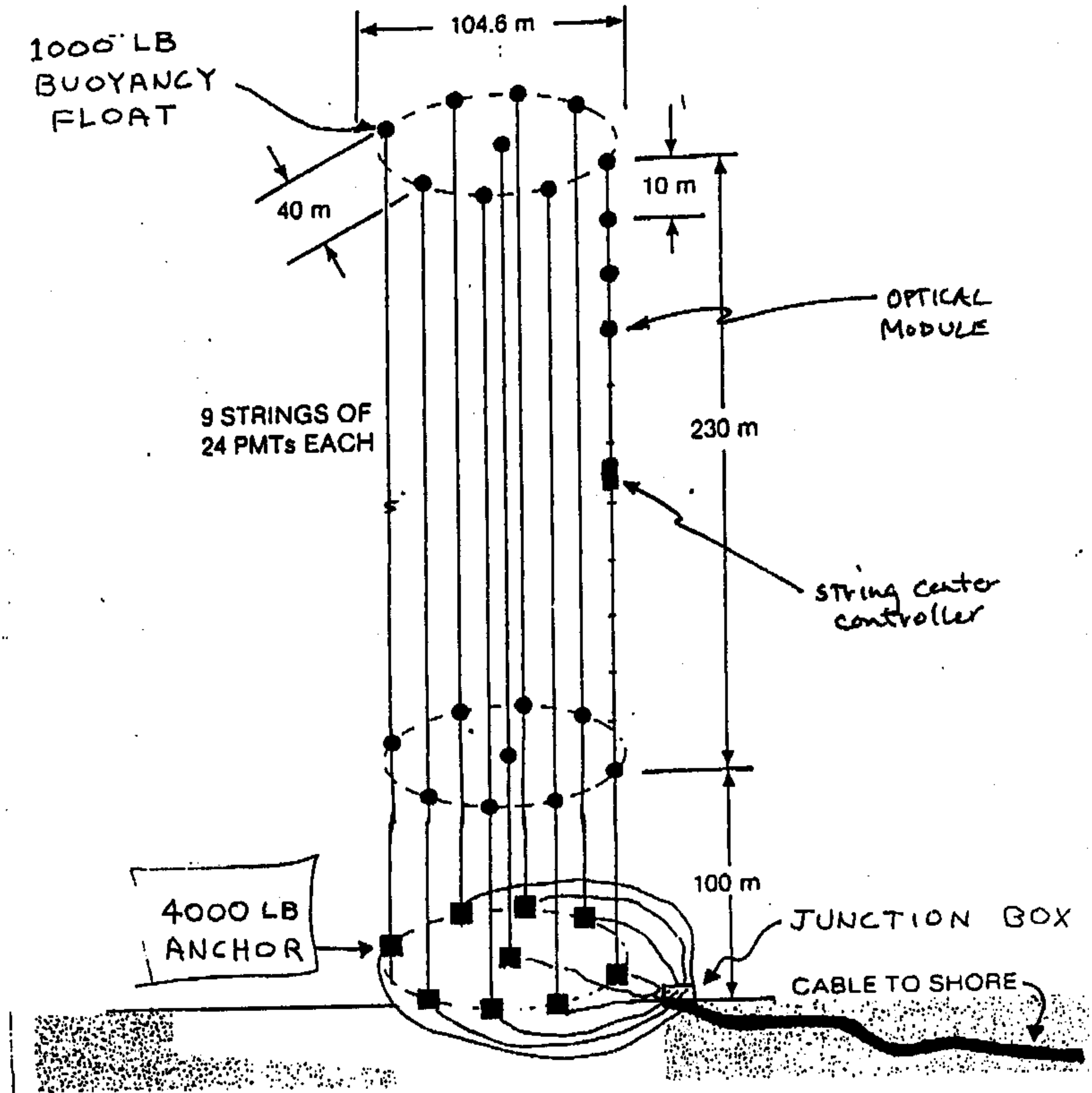
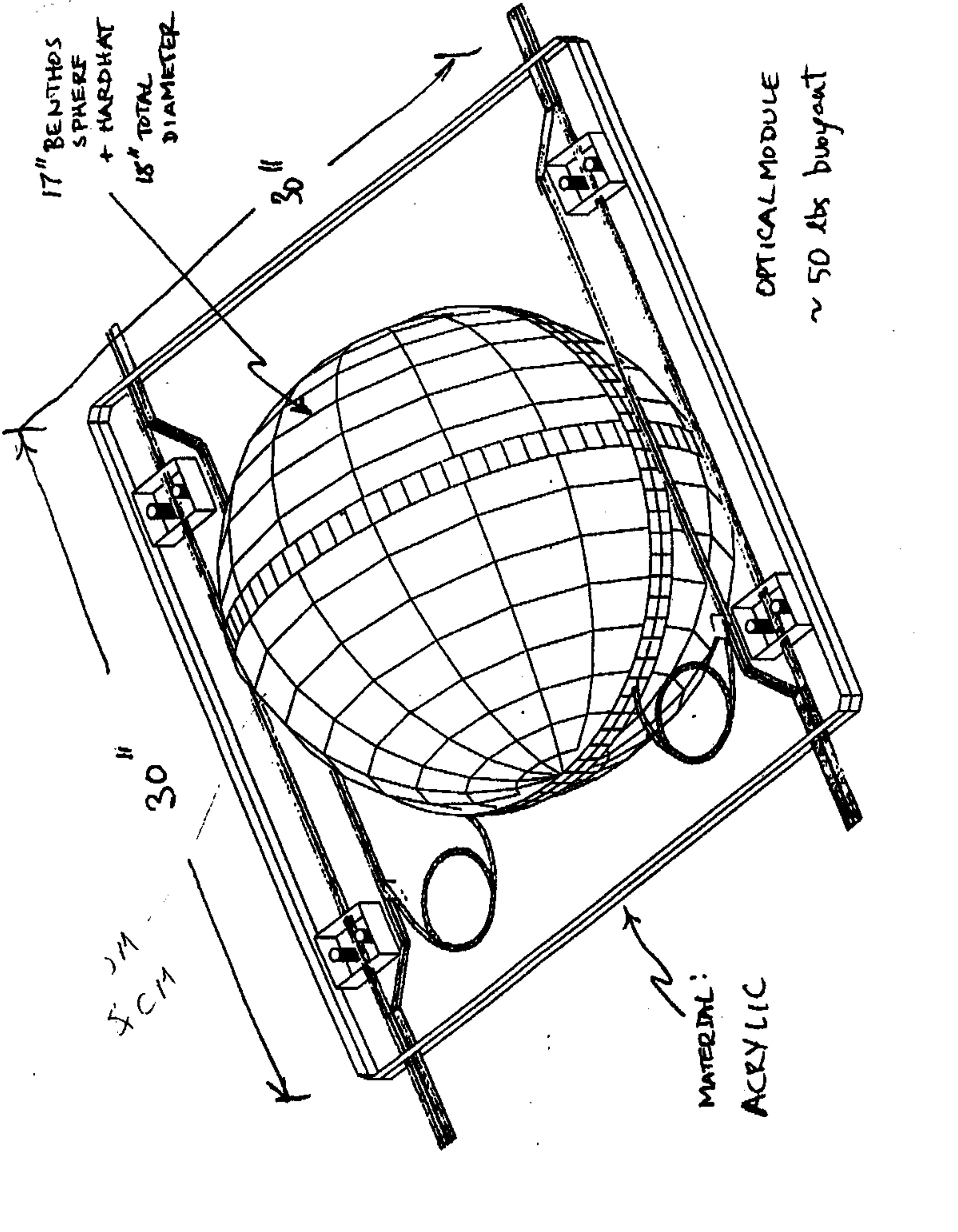
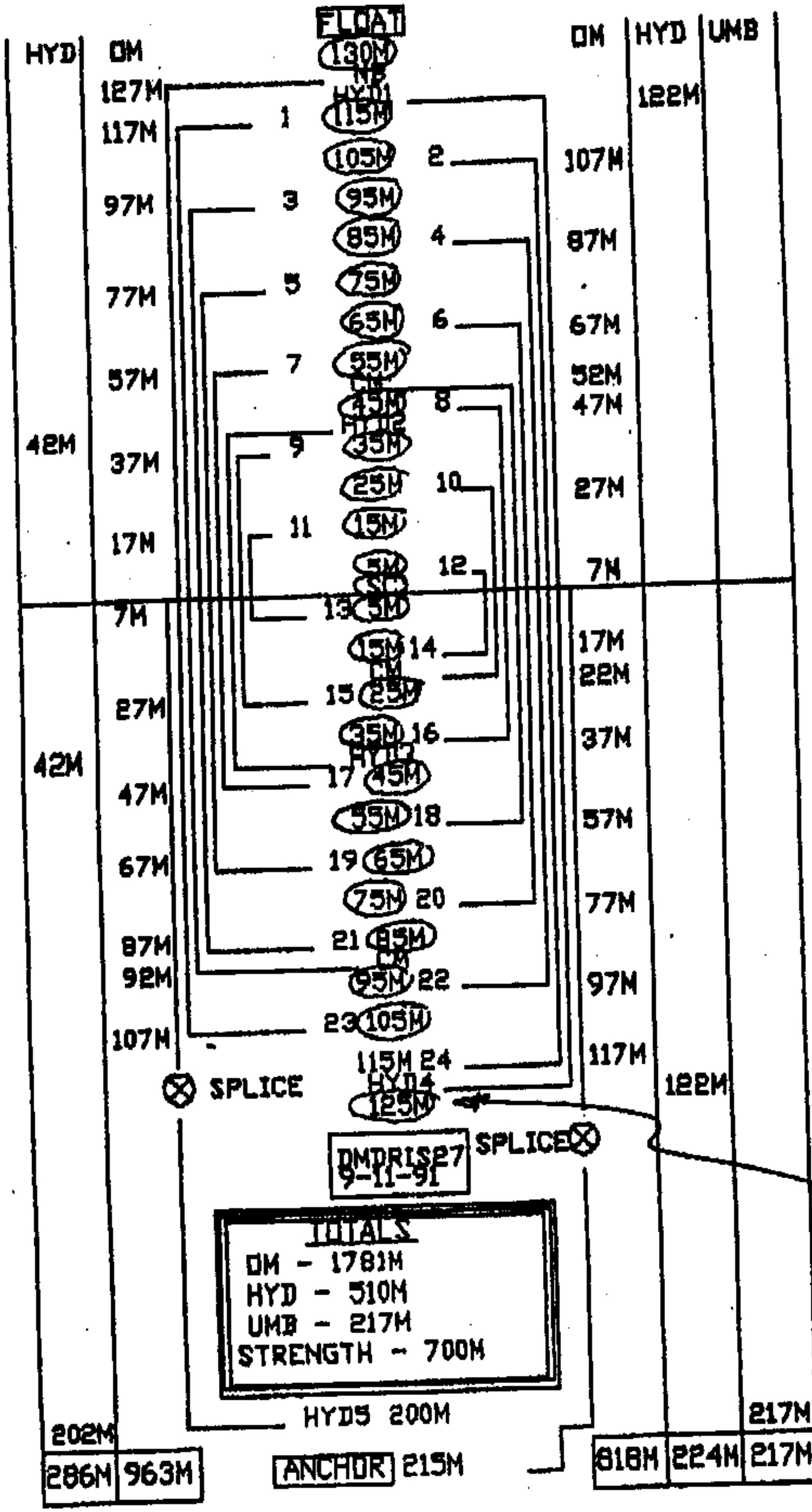


FIGURE 1. DUMAND STAGE II ARRAY.


17" BENTHOS SPHERE + HARDHAT
18" TOTAL DIAMETER
30"
30"
OPTICAL MODULE
~ 50 lbs buoyant
MATERIAL:
ACRYLIC



SCHEMATIC OF MODULE POSITIONS

OPTICAL MODULE

UMAND STRING SCHEMATIC

--PG
19 SEPT 91

FLOAT 375m +4450 N (positive==buoyant force)

NB 340m -130 N NB== Niel Brown environmental unit

HYD1 335m -10 N HYD== hydrophone, 2cm X 10 cm cyl,

OM1 330m +220 N OM==optical module, 0.45m diam sphere in 80cm X 80cm X 2cm plexi frame

--- 326.7m ||== quad riser: 2 electro-optical, 2 tensile
EO: ~2 cm diam, T: 16 mm diam

--- 323.3m spreader: 2.5 cm diam. PVC pipe, 0.8 m length

OM2
:
OM7 270m-320m +1320 N repeat pattern OM1-OM2 5 times

CM1 265m +220 N CM == calibration module, shape similar to optical module

OM8 260m

HYD2 255m -10 N

OM9
:
OM12 +880 N repeat pattern OM1-OM2 3 times

-SC- 215m -300 N SC== string controller 0.2 X 1.2 m cylinder vertically mounted

OM13 210m +220 N
: repeat pattern OM1-OM2 once
OM14 200m +220 N

CM2 195m

OM15 190m +220 N
: repeat pattern OM1-OM2 once
OM16 180m +220 N

HYD3 175m -10 N

OM17 170m
: +1100 N repeat pattern OM1-OM2 4 times
OM21 130m

CM3 125m +220 N

OM22 120m
: +660 N repeat pattern OM1-OM2 twice
OM24 100m

|-----| WET WEIGHTS tare height, with spreaders every 10 m. Dual tensile risers.
:
xxxxxxx 1.5m -9000 N anchor A: ballast for released string
A A A A: dual parallel acoustic releases
xxxxxxx 0.5m -10000 N anchor B: fixed bottom ballast
xxxxxxxxxxx