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PRELIMINARY ANALYSIS OF A DEPLOYMENT SCENARIO FOR THE DUMAND CABLE, JUNCTION BOX AND THE FIRST DETECTOR STRING

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1. INTRODUCTION

The Deep Underwater Muon and Neutrino Detector (DUMAND) project consists of an array of ultra-sensitive photodetectors which are to be deployed and moored to the bottom in 4800 m of water off the west coast of the Island of Hawaii. The DUMAND project will consist of nine arrays of instruments (denominated strings), placed on an octagonal pattern, in a 100 m diameter circle (see Figure 1). Eight of the strings will be placed around the perimeter, and one in the center. The array center string will have the main junction box located at its base, and the cable to shore will therefore depart from that point. The surrounding eight strings will have jumper (umbilical) cables, emplaced by submarine (or alternatively by remotely operated vehicle), connecting each base to the junction box.

Each 330 m tall instrumented string will be bottom tethered, but freely floating. The main optical instrumentation will begin 100 m above the bottom, staying above any cloudy bottom layer. A 100 m long rope with a float at its end will be attached to the end of the instrumented string. The string consists of 24 optical modules (OM's), 15 inch photomultipliers and electronics in a 17 inch Benthos glass pressure housings, 3 laser calibration modules (CM's), 5 hydrophones (HM's) some ancillary environmental monitoring (EM's), and the string center controller (SCC). We do not need to go into the functioning of the system here, aside from pointing out that the instruments are all connected to the SCC, and the SCC communicates to the shore via the umbilical cables and the junction box. The strings (at the SCC) receive all power and commands from shore, and transmit responses and fast data in a 625 mbd data stream back to the shore.

The instrument strings actually are suspended with a dual cable, with 30 inch spacing between the two riser cables, each of which consists of a bundle of fiber optic and electrical pairs connecting to each module from the SCC. The modules are located in the string like rungs in a ladder, with the OMs at 10 m intervals, and the other instruments at various locations in between OMs. There are also spreader bars, to prevent cable twist, at 2.5 m intervals. The tension is carried by Kevlar ropes. At the top of the string is syntactic foam float, with 1250 pounds of buoyancy, enough to keep the string acceptably straight (deviations typically less than a degree from the vertical) in the ocean bottom currents. At the bottom is an anchor package with umbilical connection and an acoustic release. The connector pack has one bi-directional single mode fiber and two 350VDC, 2A, power wires, and has connectors on both ends. The release is for emergency string retrieval without the necessity of mobilizing a submarine (which is the backup release mode).

The junction box, located at the terminus of the shore cable and at the base of the first string to be deployed, is a large passive device mainly serving as a platform to carry the connectors for the strings. The junction box is about 2.6m x 1.7m x 1.2m and has an approximate wet weight of 3,500 lb. Functionally it serves to fan out the power to the strings in parallel, distribute the 12 fibers in the shore cable [9 for the strings, one for the Junction Box Electronic Module (JBEM) and two spares], provide attachment for the 4 responders, and as terminal for the sea-water power return electrode.

The site is approximately 25 km West of Keahole Point, Hawaii, located at 19° 42' 30" N, 156° 19' 30" W, and a depth of 4760 m, on the edge of a Hawaiian subsidence basin, see Figure 2. The bottom has shallow sediment near the base of the slope from the Island, and is barren and the slope is only a few meters per kilometer. The cable run to shore is a steady climb, straight with 2 doglegs of less than 10 degrees, and the slope appears to be rather smooth, without major cliffs of large rocks until the last kilometer near shore where it is quite rough.

The deployment operations for the DUMAND project have been subdivided in three stages, namely: (1) place the first string and the centrally located junction box, and deploy the fiber optic cable to shore, (2) place the rest of the strings, and (3) connect the eight strings to the junction box using an AUV or ROV.

Makai Ocean Engineering previously completed some preliminary work on the phase (2) of the deployment. Specifically, Makai concluded that the strings could be deployed from a surface ship without the need of an Autonomous Underwater Vehicle (AUV) or a submarine as long as the ship had a station keeping capabilities of ± 20 meters. This study recommended to measure the bottom ocean currents (last 400 m to 500 m of water depth) during the deployment of the strings to increase the degree of placement accuracy.

The present study only focuses on the first phase of the deployment, namely the deployment of the first string, junction box and shore cable.

The main differences between the proposed deployment scenario and previous deployment scenarios considered is that this deployment scenario relies on the use of one ship only, the ship used in this analysis is the C/S Charles Brown which does not have good station keeping capabilities, and the cable is laid from the DUMAND deep water site to shore. The use of other ship with better dynamic positioning capabilities and with less tendency to heave and pitch should facilitate the deployment operation. The deployment scenario proposed tries to incorporate simplicity, reliability and low cost as well as the possibility of string retrieval if a problem arise during the deployment of the junction box.

2. GOALS

The main goals of the selected deployment scenario are:

- Reliability and simplicity
- Low cost (e.g. the use of a single ship and a ship of opportunity)
- String, junction box and shore cable must be connected before deployment
- Ability to retrieve system during first stages of the deployment
- Continuous monitoring of string components during deployment
- Sequence of operations must be tested before final deployment

3. DEPLOYMENT OVERVIEW

— The basic deployment plan is depicted in Figures 3 and 4 as a sequence of snapshots. The intend is to lower the string in a up-side down configuration. The string is connected to the junction box which in turn is connected to the shore cable. The use of a sacrificial anchor and a rope will facilitate the inversion of the string which will occur once the junction box touches the bottom and the shore cable has been laid. The basic steps involved in the deployment follow (a more detailed explanation of each of the steps involved and the problems that could arise are described in the next sections).

(1) A 3,500 lb steel anchor with 450 m of sacrificial line are lowered from the cable ship. A release is attached near the end of the 450 m long sacrificial line before is connected to the string float.
(2) The string float (1250 lb buoyancy) is attached at the end of the sacrificial line. An additional 3,000 lb buoy is temporarily attached to the string float to make the overall system buoyant during the early phases of the deployment.
(3) The ship's Zodiac is used to pull the temporary buoy away from the ship while the deployment of the string takes place from the ship.
(4) Once the string is fully deployed horizontally on the surface the junction box will be lowered from the cable ship. As the junction box sinks in the water, the temporary buoy is detached from the string float. The anchor-float-string system sinks towards a vertical position. An almost vertical configuration is finally achieved as the junction box is lowered and the cable vessel moves forward.
(5) Deployment continues until anchor touches the bottom. A few extra meters of cable are paid out from the ship to ensure proper anchor placement. The cable ship moves on a straight line as the junction box is lowered.
(6) Junction box is properly placed on the bottom at a distance of about 600 m away from the anchor.
(7) The cable ship proceeds to lay the cable towards shore.
(8) The string float is released from the sacrificial line, allowing the DUMAND string to adopt its final vertical position.

4. DEPLOYMENT OPERATION

4.1. CABLE SHIP

The ship of choice in this analysis is the AT&T vessel the Charlie Brown, a cable repair ship semi-permanently based in Honolulu supported by a consortium of ocean cable companies to be available for emergency repair operations throughout the Pacific. The ship goes to sea several times per year for practice operations, since the real cable problems occur only once in several years. The AT&T people are thus amenable to an operation in Hawaiian waters that will give them practice, not cost them too much, and which will generate some goodwill and publicity for their corporation. It is important to mention that the same deployment scenario can be carried out from other cable ships. The use of a ship with better dynamic positioning capabilities and with less tendency to heave and pitch than the C/S Charles Brown will facilitate the deployment operation.[1]

— The C/S Charles Brown has cable tanks which can easily accommodate the shore cable, including the splice boxes every 8 km. The splice boxes are roughly 6 inches in diameter and 2 feet long, and were needed because the existing technology does not yet reliably support the manufacturing of a single tube containing the 12 fibers in one long run. The cable is 14 mm in diameter and has 36 km total length, leaving about 6 km (20%) spare length.

The ship has a large double bow sheave (12 feet in diameter), and they normally lay off the bow, with the cable streaming either down (in slow operations) or back and down in a laying operation. There is no problem with cable fouling due to the substantial overhang of the bow sheave. There are double traction winches and traction motors between the bow sheave and the storage tanks.

There is also a comfortably large tunnel through the middle of the superstructure which permits passing equipment and cable from one end of the vessel to the other without difficulty. The plan is to place the instrument string shipping container on the ship's stern and pass the instruments forward through this tunnel.

Little problems are anticipated with putting the equipment aboard as the vessel has more than adequate space and no significant special gear is needed except at the bow gantry for string and junction box overboarding.

It should be noted that though the ship has twin screws and a bow thruster, it does not have real dynamic positioning capabilities. This means that we cannot precisely control the ship position during the lowering operation and will have to accept a 100 m or so uncertainty in placement of the junction box, which fortunately poses no problem for the deployment of the first string. The ship also does not have an integrated navigation system, so navigation information will have to be presented to the bridge via video terminal which will be installed by DUMAND personnel. The basic navigation equipment will consist of one video screen driven by a computer which will display the actual and the desired ship position. This information will be presented to the helmsman in real-time to allow him to make the necessary adjustments to the ship speed and course. A video screen will also be made available to the cable engine operator showing the difference between the length of cable that should have been paid out at any given time minus the actual length of cable that has been paid out. This information will be used by the cable engine operator to adjust the cable pay out rate as necessary. Information on transponder locations will also be displayed to monitor the shape of the string-float-anchor system as the deployment takes place.

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[1] *Since this document was originally prepared, plans for ATT ships in Honolulu have changed significantly. Appendix 1 discusses the alternatives to the use of the vessel Charles Brown.*

4.2. SACRIFICIAL ANCHOR AND ROPE DEPLOYMENT

4.2.1. SEQUENCE

— Once the ship is close to the selected site, the sacrificial anchor and rope will be deployed off the bow of the ship (see Figure 5). This operation continues until the whole length of the sacrificial line has been paid out. Note that a release will be attached near the end of the sacrificial line.

4.2.2. EQUIPMENT

The parameters analyzed to select the weight of the anchor are:

- Anchor material selected such that added mass is reduced and does not contribute significantly to the dynamic tensions induced during the lowering operation. Steel was selected for this.
- The weight of the anchor must be as low as possible to minimize the total static tensions measured at the top of the shore cable during the string deployment. The intent is to minimize chances of failure of the shore cable due to high dynamic tensions induced by ship motions.
- Weight of the anchor must be large enough to provide a reasonable sinking rate for the anchor-float-string system. At the same time, once on the bottom, the anchor must have enough holding capacity for the deployment of the junction box (i.e. dragging of the anchor on the bottom must be avoided if possible).
- Weight of the anchor must be enough to avoid snap-loading in the different sections of the string (discussed in more detail later).

Based on those constrains the anchor selected has a total wet weight of 3,500 lb. The anchoring system is composed of two lump steel weights, weighing 2,200 lb and 800 lb respectively and a Danforth steel anchor weighing 500 lb. The 2,200 lb weight will be located about 50 m above the 800 lb weight along the sacrificial rope, which in turn will be attached 15 to 20 meters above the 500 lb Danforth anchor. The 2,200 lb weight will more than compensate for the vertical pull (buoyancy) of the float and the glass balls. This will avoid having slack (zero tension) in the section connecting the junction box and the instrumented string when the anchor reaches the bottom. By avoiding zero tension in this section of the string one avoids the possibility of putting twists in the string due to rotations of the junction box when the anchor touches the bottom. The 800 lb weight will rest on the bottom and allow the Danforth anchor to dig in the ground increasing its holding capabilities and avoiding dragging. With an anchor weighing 3,500 lb the terminal velocity of the anchor-float-glass balls has been estimated to be 1.4 m/sec.

The sacrificial rope connecting the anchor and the float has been made 450 m long. Computer simulations using a vessel with the positioning capabilities of the cable vessel Charles Brown (station keeping of $\pm$ 1 ship length in sea state 3) showed that a 450 m long sacrificial rope would be enough to accommodate for inaccuracies in ship position and to avoid large values of tension on the anchor, which would otherwise require a heavier anchor. For the selection of the sacrificial rope the following parameters were considered:

- The period of resonance of the sacrificial anchor-rope system must be different from that of the ship.
- Rope must provide a large safety factor (over 5).

On one hand, it would be desirable to use a rope with good shock mitigation and elongation properties to decrease dynamic tensions, and partially decoupling the anchor mass from the rest of the system. In this case, an alternative is to use a 7/8" SAMSON 2-in-1 Nylon Braid rope with a rated breaking strength of 28,300 lb. This rope would provide a safety factor of 8 with respect to the value of static tension. Under a tension of 3,500 lb, this rope will stretch 29 m and the anchor-rope system will have a period of resonance of 12.3 seconds (calculations not shown), which is larger than that of the ship in pitch and heave. On the other hand, if snap loading in the section connecting the junction box and the instrumented string is going to be avoided or at least minimized, one would not want to decouple the anchor from the rest of the string. In this case one could potentially use lines with low stretching properties which could generate periods of resonance smaller than those of the cable vessel. Examples of these ropes are: (1) a 3/4" SAMSON Kevlar 12-strand single braid rope with a breaking strength of 42,000 lbs (under a tension of 3,500 lb this rope would stretch 3.5 m and the anchor-rope system would have a period of resonance of approximately 3.9 seconds), or (2) a 1 1/4" SAMSON Stable Braid (100 % Duron/Polyester 2-in-1 braided) with a breaking strength of 53,000 lb (under a tension of 3,000 lb, this rope would stretch 4.7 m and the anchor-rope system would have a period of resonance of 4.5 seconds).

In terms of the release mechanism to be used there are basically two choices. During the deployment operation there is really no need to have a release that could actuate at any specific time (e.g. acoustic release). Then, a cheap choice would be to use a timer release. To increase reliability two or three releases in series could be used (e.g. one or two timer releases and a corrodible link). If the string needs to be retrieved due to unexpected problems during the early stages of the deployment, it would be preferable to have an acoustic release, so that the anchor could be detached at any desired time and the string could float to the surface for retrieval. However, a vertical retrieval would also be possible if properly planned. In this case, the ship should be moving forward during the retrieval operation to keep the instrumented string taught and at an angle from the vertical to minimize snap loads.[2]

4.3. FLOAT DEPLOYMENT

A cylindrical syntactic foam float 3.5 feet in diameter, 6 feet high and with a net buoyancy of 1250 lb will be attached at the end of the sacrificial line. A ring will be attached near the end of the sacrificial line, below the release. As the end of the sacrificial rope is lowered in the water, the float will also be lowered from the side of the ship using another line (as is normally done with buoys on the Charles Brown). It is desired to make the connection between the float and the ring aboard the ship instead of in the water to ensure a proper connection.

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[2] *Note that these releases must operate properly when the cable is in a vertical as well as in an inclined position (e.g. when the junction box sits on the bottom and an arch shape is formed by the string and sacrificial rope, as depicted in Figure 10).*

Once the ring and the float are in the water, the float will be pulled around to the bow of the ship. At the same time the Zodiac boat that is aboard the ship will be launched as well as a spherical, 58" in diameter, steel buoy. This buoy has a net buoyancy of 3,000 lb and can be found as a surplus at Snug Harbor (it is currently used by the State of Hawaii for Fish Aggregation Devices).

The 58" steel buoy will be attached by a short line (approx. 4 m long) to the syntactic foam float and be towed by the zodiac (see figure 6a). The sacrificial line will then be lowered a few more meters to allow the float and the 58" buoy to take the load of the system (see figure 6b). Once slack, the sacrificial line could be released from the vessel if a double line going from the ring to the vessel is used. A back-up alternative for this operation is to use a diver from the Zodiac to release the slack sacrificial line above the ring (see figure 6c). The zodiac will pull away from the main cable vessel as the first section of the string begins to be deployed (the Zodiac on the vessel Charles Brown has 2, 45 hp outboard motors and can be launched and retrieved in sea state 4).

The deployment of the float does not represent a real problem in the overall deployment operation. There are several variations of the sequence described above that could be used to deploy the syntactic foam float. The exact sequence used will depend on the equipment available and final deck arrangement on the Charles Brown.

4.4. STRING DEPLOYMENT

4.4.1. SEQUENCE

Briefly, the overall string consist of three sections, namely:

- A 100 m long single line connecting the syntactic foam float with the instrumented string.
- A 230 m long instrumented string. This section has about 30 glass balls with the optical modules and other components. These sensors are tied on each side to 1/2" Kevlar ropes acting as riser cables.
- A 100 m long string consisting of 2, 1/2" Kevlar ropes and an electrical cable.

The first section of the string can be deployed through the bow of the ship. As the second section (instrumented section) of the string is reached, the deployment will be slower and will be a "hand-over-hand" process. Attachment points will have to be provided along the array (every 5 to 10 m) such that the sensors are deployed or brought up on deck (in case of retrieval) a bit at a time. The lifting tool will be released near the waterline with a hand operated tether from the bow, after tension has been taken up at the next lifting point.

The string will be passed forward by hand through the central ship's tunnel, on skids pads for each module, and keeping the modules covered from extended direct sun exposure. It is expected that between 6 to 7 modules at a time will be out on deck during this operation.

Finally the 100 m long section with no instruments and only spreader bars will be reached. This section will be prepositioned back towards the bow of the ship from the string container, where it connects to the JBEM section and the junction box itself.

— As this operation takes place, the zodiac will be pulling on the 58" buoy to keep the string "straight" and avoid entanglement (see Figure 7). Under this configuration, ship motions will be easily absorbed by the system which is in a "slack" condition.

4.4.2. EQUIPMENT

The 100 m long single string attached to the float could be a 1" SAMSON Nystron Braid (composite nylon/polyester 2-in-braided rope). During the vertical deployment and retrieval the static tension in this section of the system will be about 2,250 lb. At this tension, we can expect a total stretch of 1.9 m over the 100 m length of rope which will be working with a large safety factor (over 15).

This line has low elongation when compared with conventional nylon ropes, but it elongates considerably more than the Kevlar ropes originally proposed. While elasticity of this section in the system is not critical during deployment, it will partially help to mitigate shocks and provide some elasticity to the system during a vertical recovery operation. The proposed rope is still stiff enough to have a natural period of oscillation of 5.3 seconds (calculations not shown), considerably smaller to the natural periods of pitch and roll for the cable vessel used.

The second (instrumented) and third section of the string will have two, 1/2" kevlar ropes on each side. Each of these ropes has a breaking strength of over 20,000 lbs and they have very low stretching properties.

4.5. JUNCTION BOX DEPLOYMENT: VERTICAL LOWERING

The junction box is set into position near the bow, all connected, and overboarded with a separate line. A short sacrificial line could be used at this point to take the load of the junction box until is in the water, at which point the load is transferred onto the shore cable. [In section 5., the possibility of using a longer sacrificial line is discussed. This longer line would facilitate the deployment of a device which would avoid cable hockles as the junction box touches down].

At this time a full system electrical checkouts will be conducted using the portable shore station aboard the vessel. If a failure has occurred the operation can be reversed.

Once the junction box is well under water (100 m to 200 m deep), the short line connecting the 58" steel buoy to the float will be released by personnel aboard the zodiac (a double line can be used for safe release). Then, the anchor-float and string will fall until a final position is achieved (see Figure 8).

Slight ship forward motion is desirable here (ship speed between 1.0 and 1.5 knots) for purposes of keeping the instrument string taught. Because of the length of the vessel, pitching is particularly dangerous, so the operation can only be performed in relatively calm seas, without large swells. Appendix 2 shows results of studies of dynamic tensions induced in the string for a number of different positions during the deployment process. These results were obtained using the program SNAPLOAD provided by the Naval Civil Engineering Laboratory. The primary results obtained with respect to the proposed deployment scenario is that operations could safely be carried out in moderate seas (up to sea state 3).

Lowering of the system with the shore cable proceeds as the ship moves forward at slow speed (1.0 to 1.5 knots) until the anchor gets close to the bottom. During this time the junction box is being lowered at a rate of no more than 60 m/min (it has been estimated that the sinking rate of the anchor-float-string system is about 85 m/min). The trajectory of the string should be calculated and monitored continuously. The preplaced and surveyed transponder network will serve for the reference frame. The active electronics on the string will permit pinging and reception using DUMAND equipment alone. The pinger on the string will send out pulses to the transponder net, with replies received on the JBEM hydrophones. The five hydrophones on the instrument string will give its shape. It only remains to monitor the response of the transponder on the sacrificial anchor to know its location. The frequencies and exact pattern of responses remain to be determined, as also is the possibility of a redundant acoustic monitoring directly from the ship using traditional hardware and possibly a contracted team with their own software and displays for the bridge. The acoustic transponder attached to the anchor will provide information on the location of the anchor in almost real time. The lowering speed will be decreased during the last 100 meters before the anchor touches the bottom while the ship moves on a straight line towards the target location.

4.6. JUNCTION BOX DEPLOYMENT: BOTTOM PLACEMENT

Once the anchor touches the bottom (transponder position attached to the anchor and possibly top cable tension will be monitored to establish anchor touchdown) 20 to 30 extra meters of cable will be paid out to ensure proper anchor placement. With the design proposed for the anchor system, there is no fear that any section of the string will go slack during this operation, and therefore no twists should be introduced in the string system as a consequence of the anchor touchdown.

At this point and until the junction box touches the bottom, the ship velocity and cable pay out speed will be controlled by using the reported "real-time" positions from the transponders attached to the junction box and anchor. Figures 9 and 10 depict the sequence for this part of the deployment at different times during a computer simulation. Figure 11 shows the cable payout lengths and ship positions as a function of time during the period of deployment in the computer simulation.[3]

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[3] *The deployment sequence depicted in Figures 9 and 10 are for a case where the whole anchor weight touches the bottom and therefore some slack is introduced in the 100 m long section of the string connected to the junction box. However, the sequence of operations and the configurations shown after the slack is eliminated can be considered to be accurate. In addition, the reader must keep in mind that the values of cable payout and ship position shown in Figure 11 are for this simulation only, and they are by no means the optimum values that should be used during the real deployment operation.*

The touchdown of the junction box can also be monitored on TV, so we can assure that the junction box is sitting correctly and that the cables are all where they should be.

4.7. LAYING SHORE CABLE AND RELEASING SACRIFICIAL ROPE

Normal cable laying then proceeds towards shore, using preprogrammed laying rates and following the slightly dog-leg course. An alternative is to have a real-time cable deployment system aboard the ship to give the bridge steering instructions. The advantage of having the cable deployment system aboard the ship instead of ship positions and cable pay out tables prepared in advance is that any contingencies (e.g. ship has to stop for a period of time) could be easily handled by the cable control system in real-time. Laying will proceed at perhaps 2 knots for reasonable steerage, and the run to shore will take about seven hours. Note that in general cable payout rate will be slightly less than ship speed because of up-slope laying. Note also that the three (or perhaps four) splice boxes must be passed overboard.

Any time after the junction box is in place and the shore cable is leading comfortably away from the junction box the float can be released from the sacrificial line to adopt its final vertical position. It is preferable to time the release the float when the shore cable has been laid to facilitate the retrieval of the anchor-string-cable system should it becomes necessary. As explained before, the release mechanism used could be a simple combination of timer releases and a corrodible link to add reliability to the system. There is really no reason why an expensive acoustic releaser has to be used other than to facilitate retrieval in case is needed during the early stages of deployment. The sacrificial rope has been selected such that will sink once released from the float. An alternative here is to further release the sacrificial rope and recover it, mainly just to prevent clutter of the array area. Such recovery could be carried out at a later time, such as when the next strings are about to be put into position.

4.8. SHORE END OPERATIONS

After arriving at the offshore termination point the ship will drop anchor. The cable will be brought near shore on floats, and then pulled through a cable pipe. Divers will be used to hook the cable to the pulling line.

4.9. RETRIEVAL PROCEDURES

In case of a contingency which requires complete retrieval of the system, the procedure could be as follow:

1. Retrieval of the shore cable using ship position and cable payout data measured during the deployment process.
2. Lifting the junction box using the shore cable. For this operation to be successful, one must be sure that no hockles are formed on the shore cable which, under tension, could kink and damage the fibers inside the cable (section 5. discusses in more detail the problem related to cable hockles).
3. Once the junction box is off the bottom and assuming the sacrificial rope has not been released yet, the shore cable would be brought up onto the ship as the ship moves slowly to

a point where the ship is directly above the anchor and the whole string is under tension. This procedure must make use of the cable payout and ship position data collected during the deployment phase.

4. Anchor can then be lifted from the bottom. Recovery of the junction box and string components is done while ship moves forward to keep the string taught all the time and minimize the possibility of snap loading.
5. Sacrificial rope and anchor are also recovered.

5. POTENTIAL DEPLOYMENT PROBLEMS THAT NEED FURTHER ENGINEERING WORK

What follows addresses some potential problems that could occur during the deployment operation as well as some conceptual solutions which should be explored further.

Currently, the main concerns are:

(1) Avoid high dynamic tensions on the shore cable. Total tension on the shore cable should be kept low. Although the breaking strength of the shore cable is 36,000 lb, it has been established that it would be desirable to keep the maximum cable tension below 50% of its breaking strength at any time during the deployment.

(2) Make sure that the junction box is properly placed on the bottom to facilitate connections of the future strings. The junction box should sit on the bottom in an upright position.

(3) Generation of hockles in the shore cable as the junction box is placed on the ocean bottom.

(4) Avoid snap loads during deployment in the section connecting the junction box with the instrumented string.

(5) Need to analyze in more detail retrieval procedures and how to deal with contingencies which could occur during the deployment or retrieval operations.

5.1 DYNAMIC TENSIONS

Due to the low stretching properties of the shore cable and the large masses of the system components, some relatively large values of dynamic tension on the cable can be expected during the early phases of the vertical deployment of the junction box. However, at this stage the total static tension on the cable will be relatively small (less than 5,000 lb), and therefore it is unlikely that the 18,000 lb limit (50% of its breaking strength) be exceeded.

As the junction box is lowered and the anchor gets close to the bottom, maximum static tensions of around 13,500 lb will be measured at the top of the shore cable. If the 18,000 lb limit is not to be exceeded, there is room for only 5,000 lb for dynamic tensions (about 38% of the static tension). Work must be done is two areas:

- Estimate the maximum values of dynamic tension that could be expected during the different phases of the deployment under the maximum sea state at which the deployment will take place; or estimate the maximum sea state at which deployment could take place such that induced dynamic tensions would not exceed 5,000 lb at any time.

- Determine how conservative is the 18,000 lb limit that has been established as a maximum tension limit.

Having answered the previous two questions, the need for a heave compensator device (RAM tensioner, elastic line, etc.) can be better assessed. Also, note that the alternative proposed later to address the possibility of hockles in the shore cable as the junction box reaches the bottom could also help to decrease the values of dynamic tensions.

As mentioned above, appendix 2 in this report presents a preliminary analysis of cable dynamic tensions induced during the different phases of the deployment under different sea state conditions.

5.2. PROPER PLACEMENT OF JUNCTION BOX

The computer modeling completed for the simulation of the lowering and placement of the junction box on the bottom provided information on the tension and angles on the cables on both sides of the junction box (shore cable and string riser).

Preliminary analysis of the different positions of the junction box as it is lowered indicate that placing the junction box in its up-right position as desired should not represent a major problem. By properly attaching the riser and shore cable to the junction box, and by building the junction box so that the center of gravity is as low as possible and centered, enough restoring moments can be generated to ensure the proper placement of the junction box. Figure 12 shows the dimensions of the junction box and system of coordinates selected (origin is at the center of gravity) while figures 13 and 14 present a sequence of the box position during the different phases of the deployment. As seen from these figures, a single point connection is proposed for the shore cable (at the top of the box, centered and in the same XY plane as the CG), while the riser cables are tied on both sides of the junction box (at the top, somewhat in between the center and the corner). Attaching the riser cables at the corner of the junction box is not recommended since once the string is in its vertical position, the buoyancy of the float could lift the corner of the junction box. The results presented in figure 13 assume that the junction box is deployed vertically down, and that the moments induced by the drag forces are small.

In spite of the apparent lack of a problem, further analysis should be carried out. It may be worth building a small model of the junction box and look at all possible combinations, even those that "should not occur" during the deployment.

5.3. GENERATION OF HOCKLES WHEN JUNCTION BOX TOUCHES DOWN

As the junction box touches down, 3,500 lb of weight are removed from the system and some slack is generated in the shore cable connected to the junction box.

The selected shore cable twists at a rate of 0.1°/ft/1000 lb of tension. This means that as the junction box touches down the shore cable could potentially untwist up to 15 turns over 4,760 m of cable due to the release of the 3,500 lb load. As the anchor load is released from the system, a small torque will be generated at the connection of the shore cable with the junction box which under slack conditions could potentially induce cable hockling. At this point, not enough analyses have been carried out to determine if hockles could be generated under these conditions. However, if in fact hockles are generated they could threaten the integrity of the cable, mainly if the junction box has to be lifted from the bottom (e.g. this could happen if the junction box is not placed properly or during a retrieval operation).

A proposed alternative to solve this problem is illustrated in Figure 15. Briefly, we propose to use a piece of elastic braided rope attached to the junction box and to the shore cable (a PMI grip could be used to attach this rope to the shore cable). The shore cable will be placed (inserted) through the rope in such a way that the radius of curvature is considerably larger than the minimum radius of curvature recommended by the cable manufacturer (14" at zero tension and 27" at 25% breaking strength). In preliminary estimates, the length of this rope has been found to be around 80 meters. It is expected that this rope will take the tension of the junction box as is lowered and also the twists induced by the shore cable when the junction box touches the bottom and slack is induced in the rope. With this set-up, lifting the junction box once on the bottom should not create a problem. Note that during the overboarding of this section of the rope a sacrificial line may be needed to avoid damage of the shore cable as it goes over the sheave.

If needed, a weight could be added at the point of attachment between the rope and the shore cable to increase the cable tension at this location. This would eliminate the possibility of generating cable loops on the shore cable above the attachment point.

5.4. SNAP LOADS IN THE STRING

In sea state III (wave heights up to 1.25 m and wind speeds of 11 to 16 knots) peak vertical sheave velocities of 3 ft/sec can be expected in the AT&T cable laying vessels (taken from AT&T Manual). The peak value of vertical sheave velocity increases to 5.5 ft/sec for sea state IV. No maximum values of vertical accelerations are given in the AT&T manual. However, for standard cable laying ships, values of vertical sheave acceleration of 0.13g to 0.18g are not uncommon for sea state IV.

Preliminary calculations of the acceleration expected in the section of the string connecting the junction box and instrumented string have been carried out. These computations make use of the net weight of the system and the total masses (including hydrodynamic masses) of the anchor, float and instrumented string. For the current design, values of accelerations of 1.68 m/sec^2 (0.17g) have been computed. These values of acceleration were computed neglecting the drag force (smaller values of acceleration could be possible in a vertical deployment where the drag forces play a significant role).

In order to avoid snap loading the values of acceleration for the junction box should be smaller than those computed for the section of string under consideration.

Some potential solutions to this problem are:

- Decrease the amplitude of motion of junction box. This could be achieved by adding an elastic nylon rope (approx. 100 m long) parallel to the shore cable at the junction box connection. This rope would partially "decouple" the motion of the junction box from that of the ship.

- Increase the elasticity of the section of the string connecting the junction box to the instrumented string. This could be accomplished by using a temporary nylon line parallel to the Kevlar ropes which would be absorbing any shock loads during the deployment operation.
- Deploy the junction box with low values of cable payout speed and moving the ship forward to keep the line taught at all times. In this case the drag force acting on the string will increase the overall static tension on the cable.

Appendix 2 presents a preliminary analysis of snap loads and cable dynamic tensions induced during the different phases of the deployment operation.

6. CONCLUSIONS AND RECOMMENDATIONS

The report has presented a viable scenario for the simultaneous deployment of the first vertical instrumented string, the junction box and the shore cable. The deployment scenario is relatively simple, reliable and involve the use of a single ship in order to minimize deployment costs. It has been shown that the use of a ship without dynamic positioning capabilities is possible as long as the ship can maintain position within ± 100 m approximately. Furthermore, the deployment operation makes use of cheap sacrificial anchors, and buoys that are readily available at a minimum or no cost.

Additionally, this preliminary study has identified the main areas where further study is required in order to ensure a successful deployment operation. The main areas where work remains to be done before a final deployment plan can be completed are:

- Once a final ship for the deployment operation is selected, further analysis on the dynamic tensions and possibilities of snap loadings on the cable and string during the different phases of deployment and retrieval must be completed. It is desired to select a ship such that heave and pitch motions under moderate sea states are small.
- Once a final ship and cable engine to be used are selected, computer simulations of the deployment operations must be completed to determine the proper combination of ship and cable engine instructions that must be followed by the ship to ensure proper placement of the string-junction box system.
- Once a section of the shore cable to be used is available for testing, the twist and torque properties of the cable must be analyzed to assess the probability of generating hockles in the shore cable as the junction box is placed on the ocean bottom.
- Retrieval procedures and contingencies which could occur during the deployment and retrieval operations must be analyzed in more detail.
- Once the final design of the junction box is completed, further analysis of the string-junction box connection and shore-junction box connection must be completed to ensure that the junction box sits properly on the bottom.

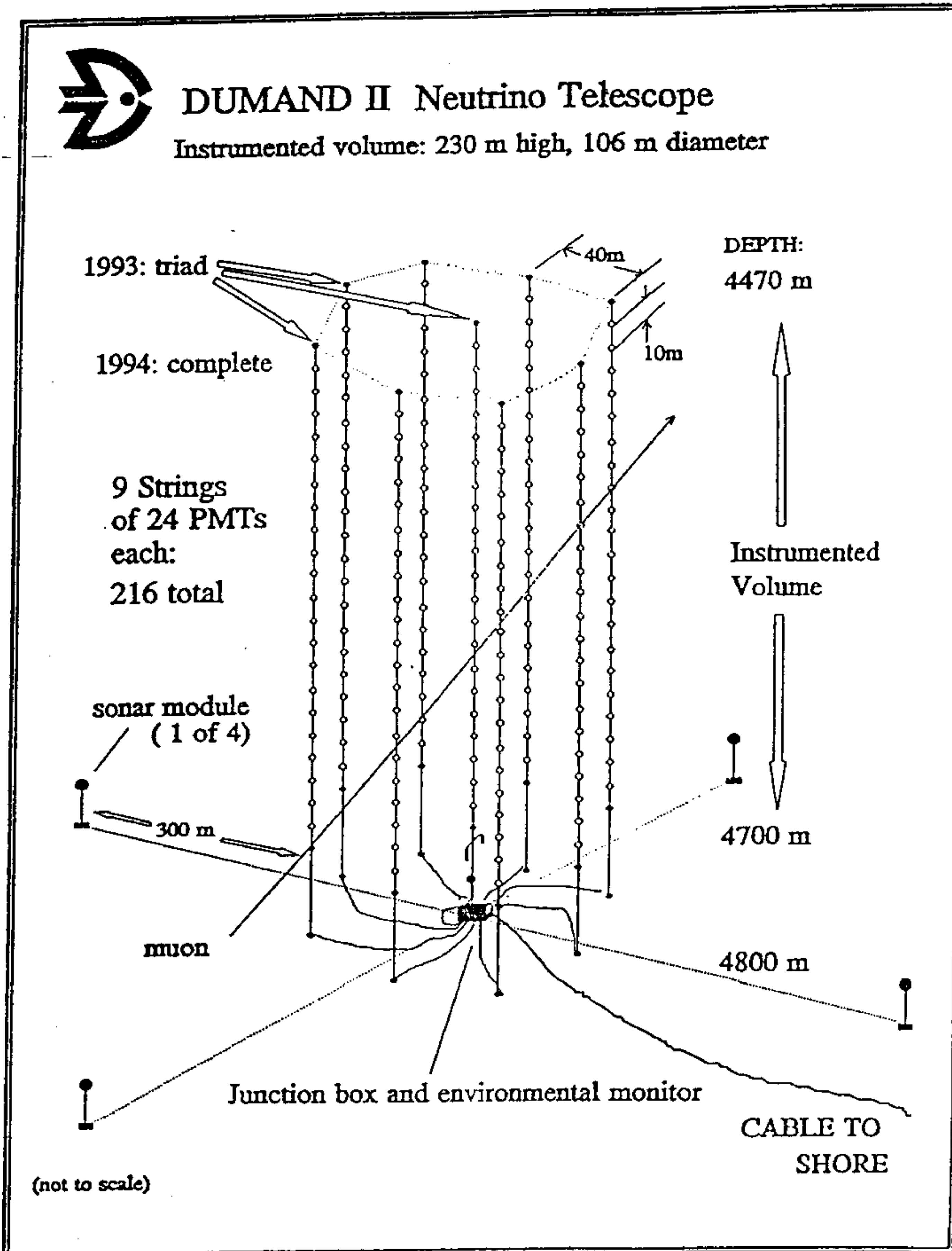

DUMAND II Neutrino Telescope
Instrumented volume: 230 m high, 106 m diameter
1993: triad
1994: complete
40m
10m
DEPTH:
4470 m
9 Strings
of 24 PMTs
each:
216 total
Instrumented
Volume
sonar module
(1 of 4)
300 m
4700 m
muon
4800 m
Junction box and environmental monitor
CABLE TO
SHORE
(not to scale)

FIGURE 1

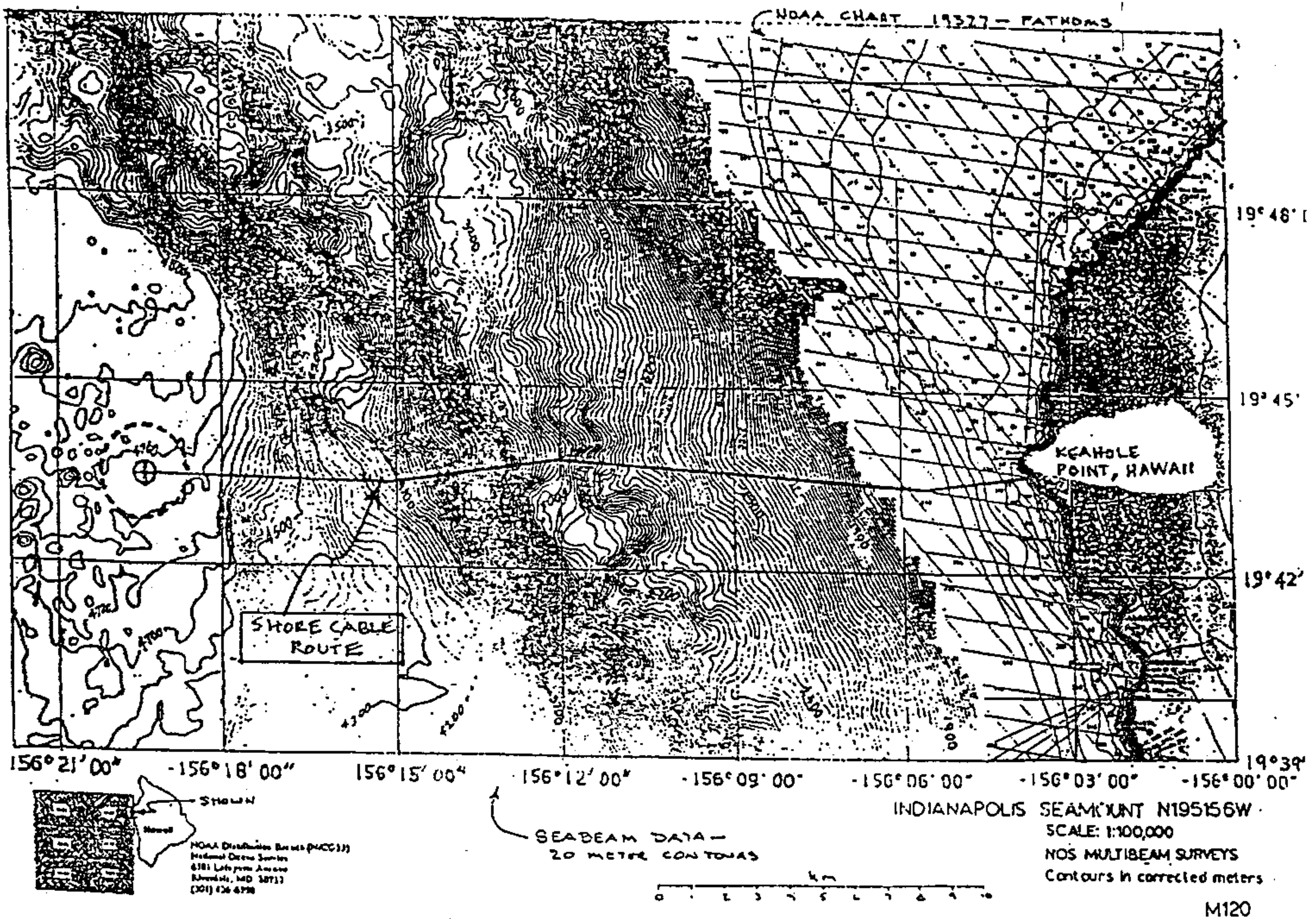

NOAA CHART 19327 — FATHOMS
19°48'
19°45'
19°42'
19°39'
KEAHOLE POINT, HAWAII
SHORE CABLE ROUTE
156°21'00"
-156°18'00"
156°15'00"
156°12'00"
-156°09'00"
-156°06'00"
-156°03'00"
-156°00'00"
SHOWN
SEABEAM DATA — 20 METER CONTOURS
km
INDIANAPOLIS SEAMOUNT N195156W
SCALE: 1:100,000
NOS MULTIBEAM SURVEYS
Contours in corrected meters
M120

FIGURE 2

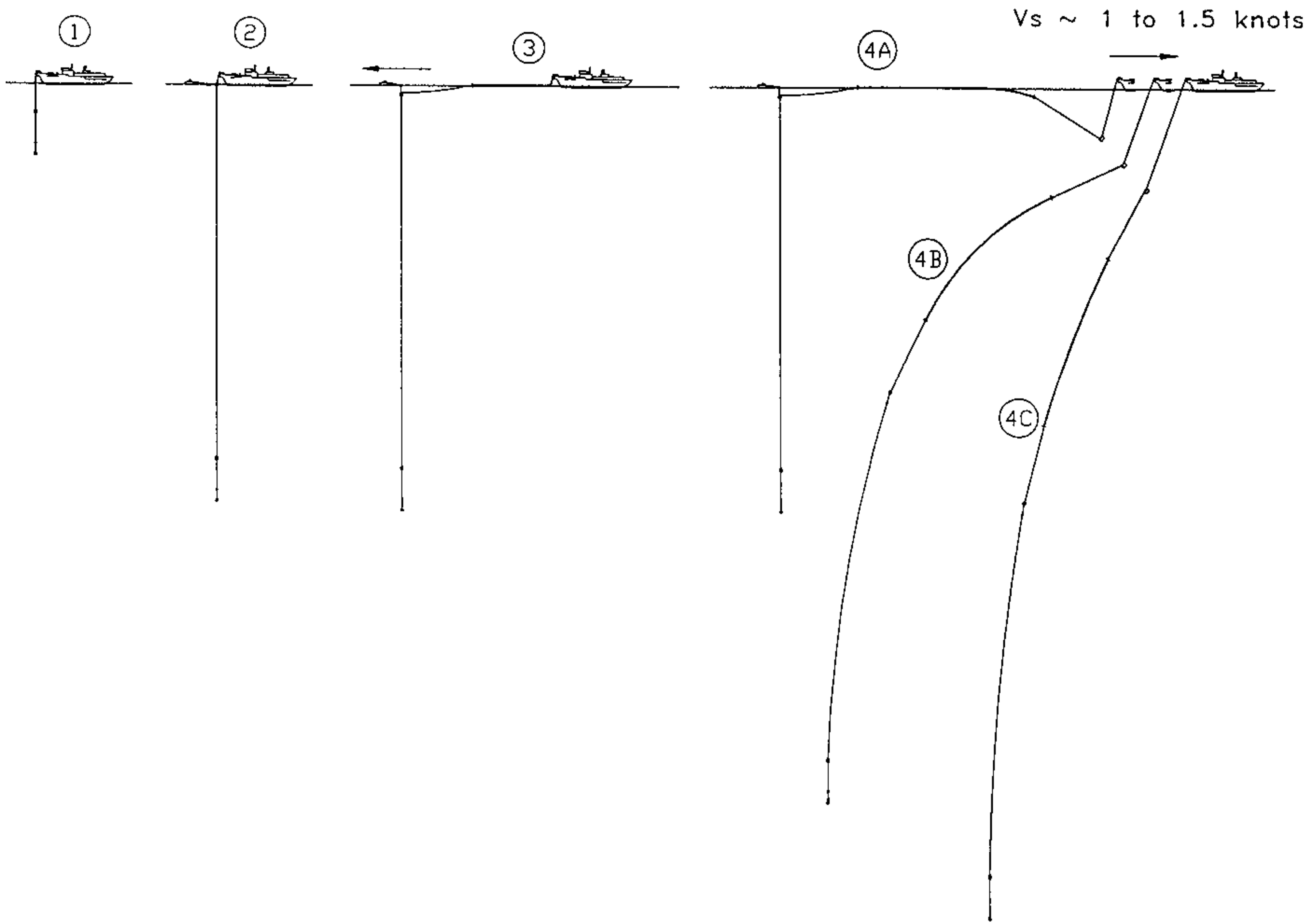


FIGURE 3. STEPS FOR DEPLOYMENT OF FIRST STRING JUNCTION BOX & SHORE CABLE

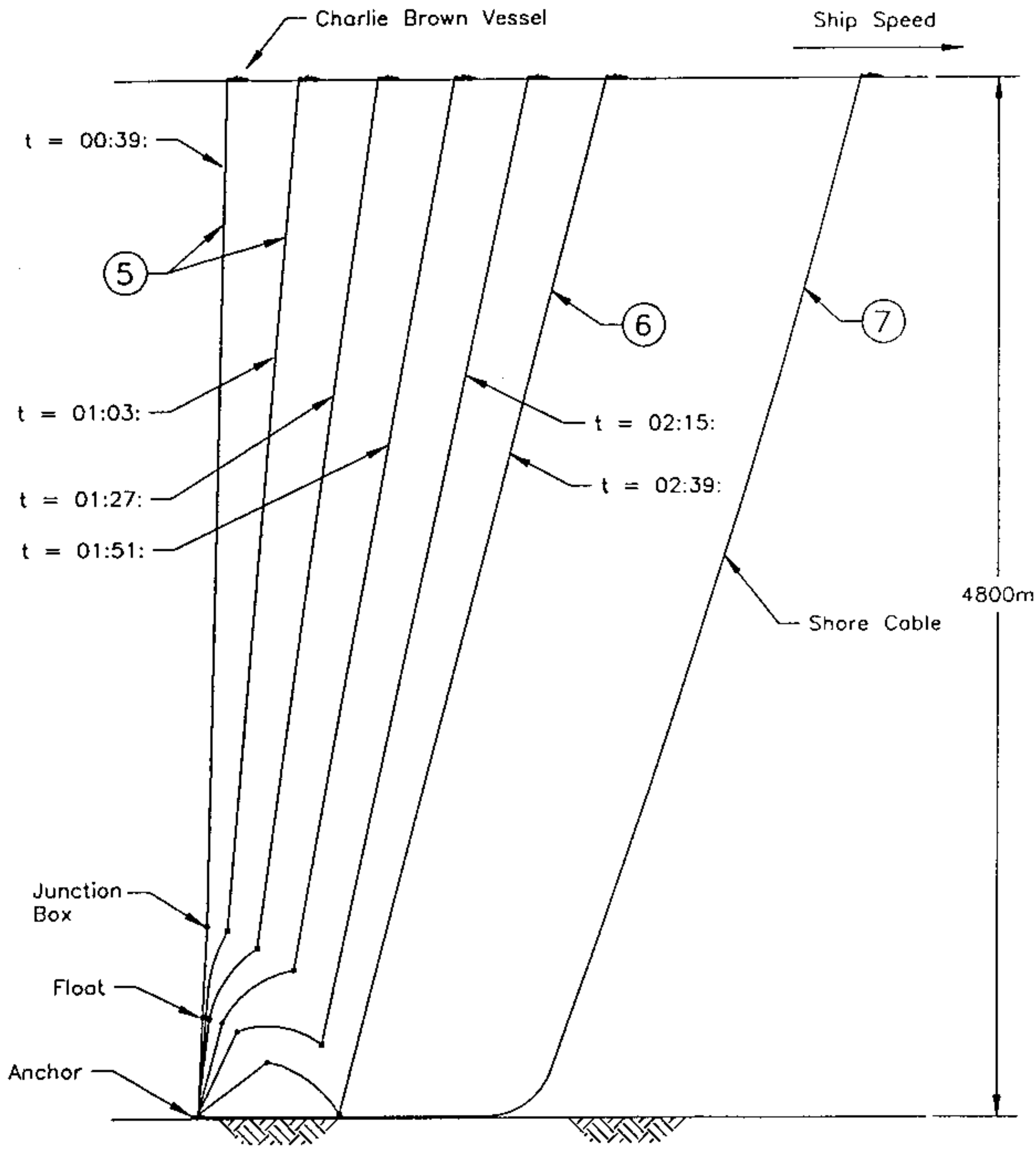


FIGURE 4. STEPS FOR DEPLOYMENT OF FIRST STRING JUNCTION BOX & SHORE CABLE

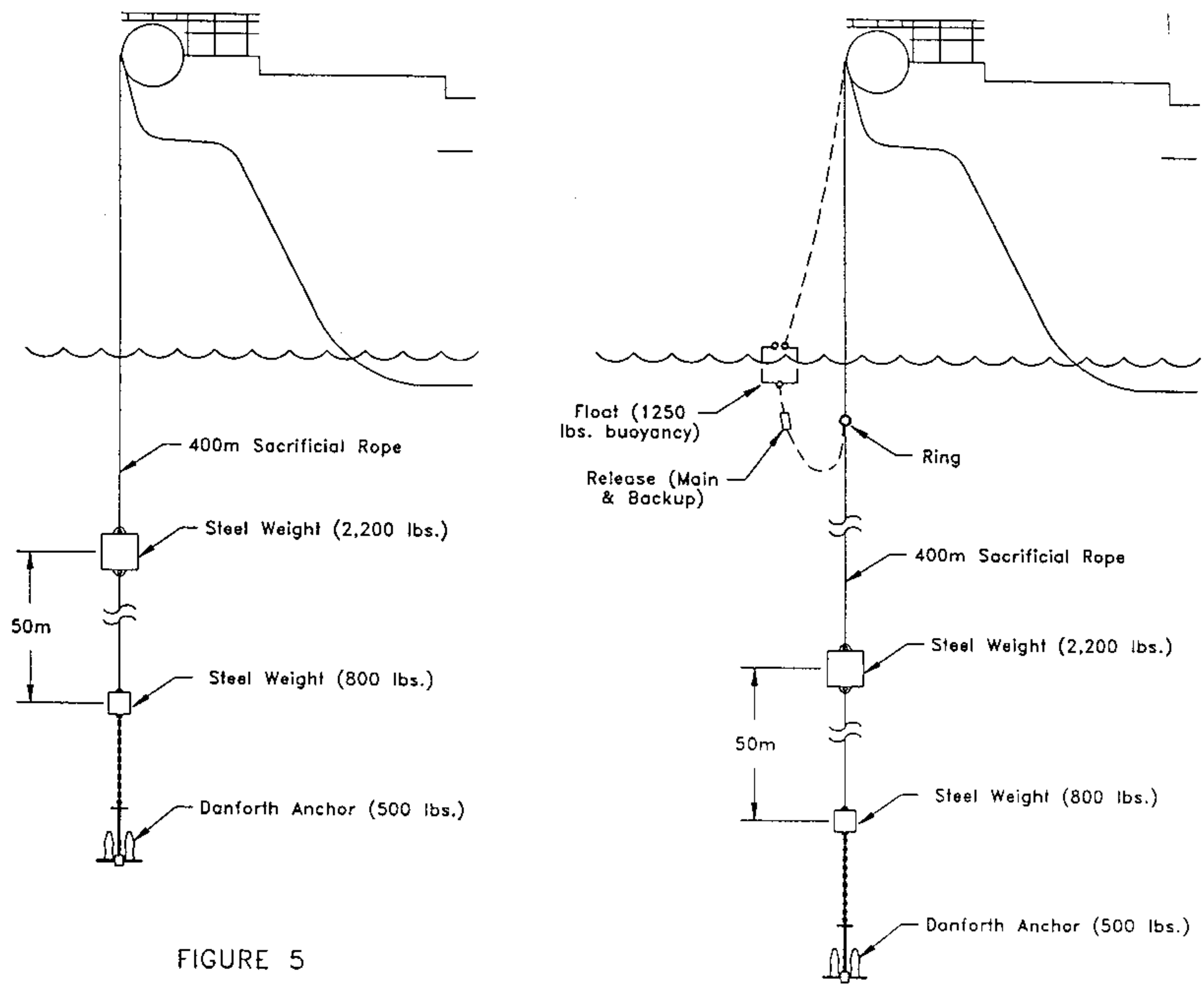

400m Sacrificial Rope
Steel Weight (2,200 lbs.)
50m
Steel Weight (800 lbs.)
Danforth Anchor (500 lbs.)
Float (1250
lbs. buoyancy)
Release (Main
& Backup)
Ring
400m Sacrificial Rope
Steel Weight (2,200 lbs.)
50m
Steel Weight (800 lbs.)
Danforth Anchor (500 lbs.)

FIGURE 5

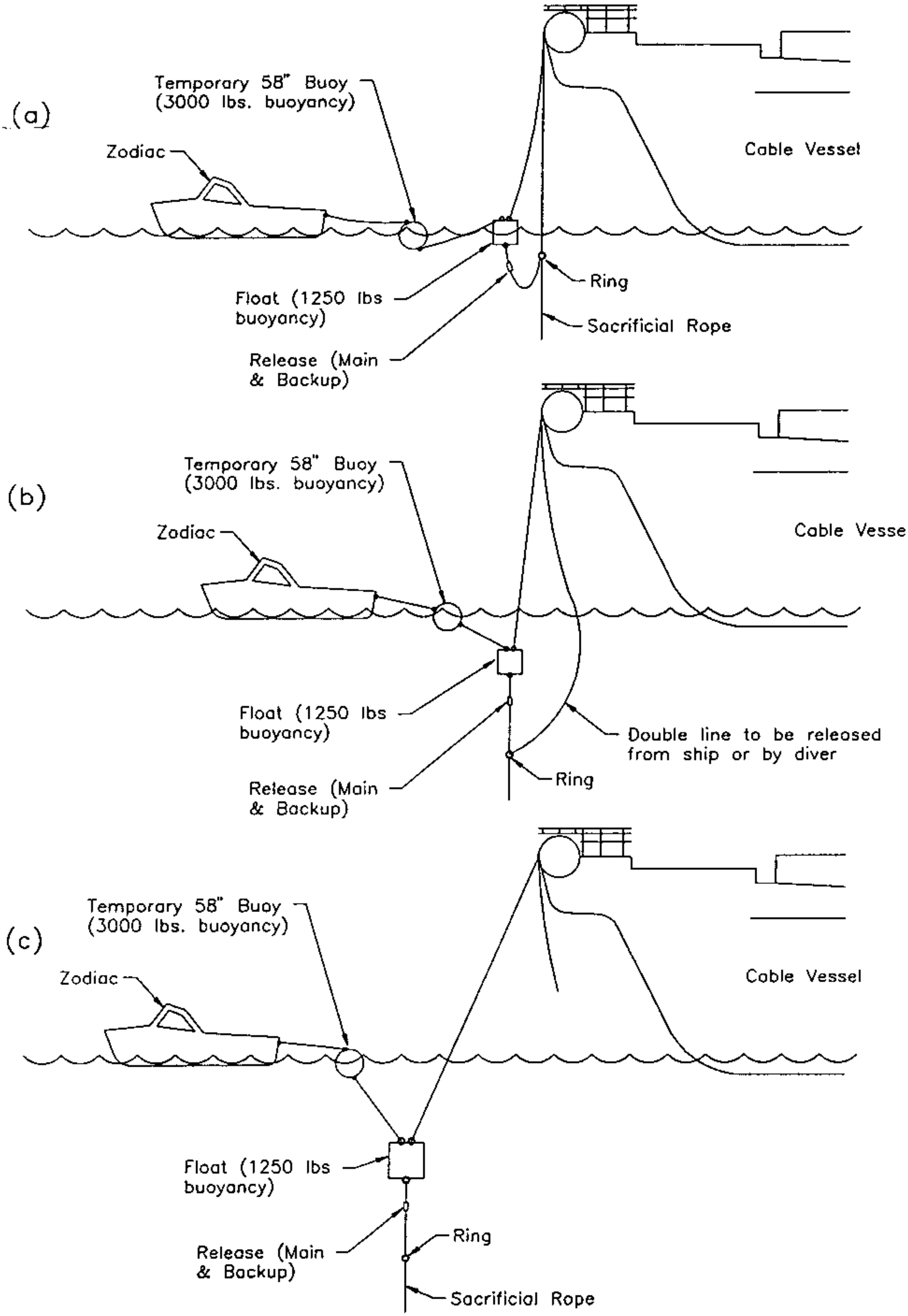

(a)
Temporary 58" Buoy
(3000 lbs. buoyancy)
Zodiac
Cable Vessel
Float (1250 lbs
buoyancy)
Ring
Sacrificial Rope
Release (Main
& Backup)
(b)
Temporary 58" Buoy
(3000 lbs. buoyancy)
Zodiac
Cable Vessel
Float (1250 lbs
buoyancy)
Double line to be released
from ship or by diver
Ring
Release (Main
& Backup)
(c)
Temporary 58" Buoy
(3000 lbs. buoyancy)
Zodiac
Cable Vessel
Float (1250 lbs
buoyancy)
Ring
Release (Main
& Backup)
Sacrificial Rope

FIGURE 6

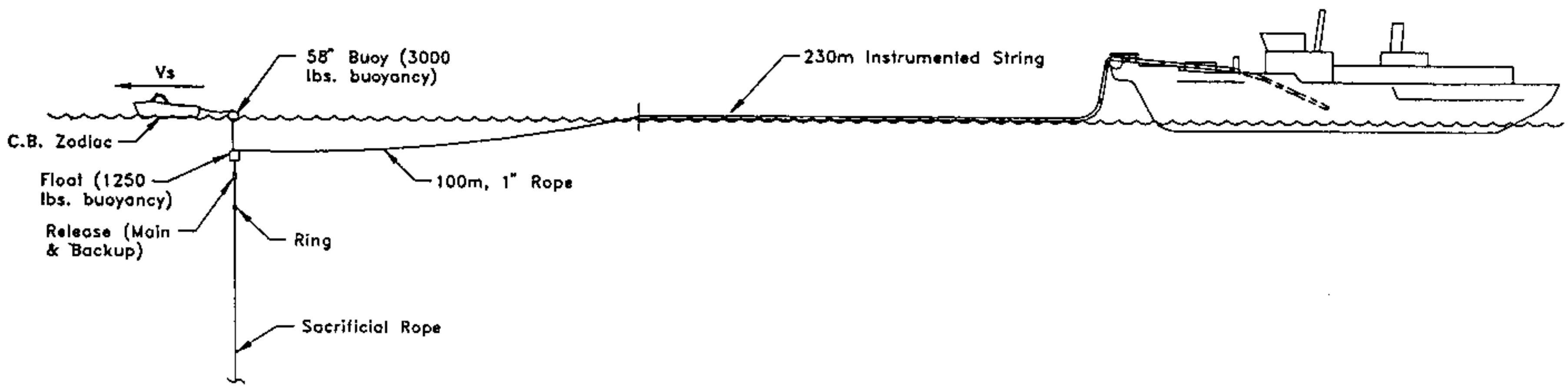

Vs
58" Buoy (3000
lbs. buoyancy)
230m Instrumented String
C.B. Zodiac
Float (1250
lbs. buoyancy)
100m, 1" Rope
Release (Main
& Backup)
Ring
Sacrificial Rope

FIGURE 7

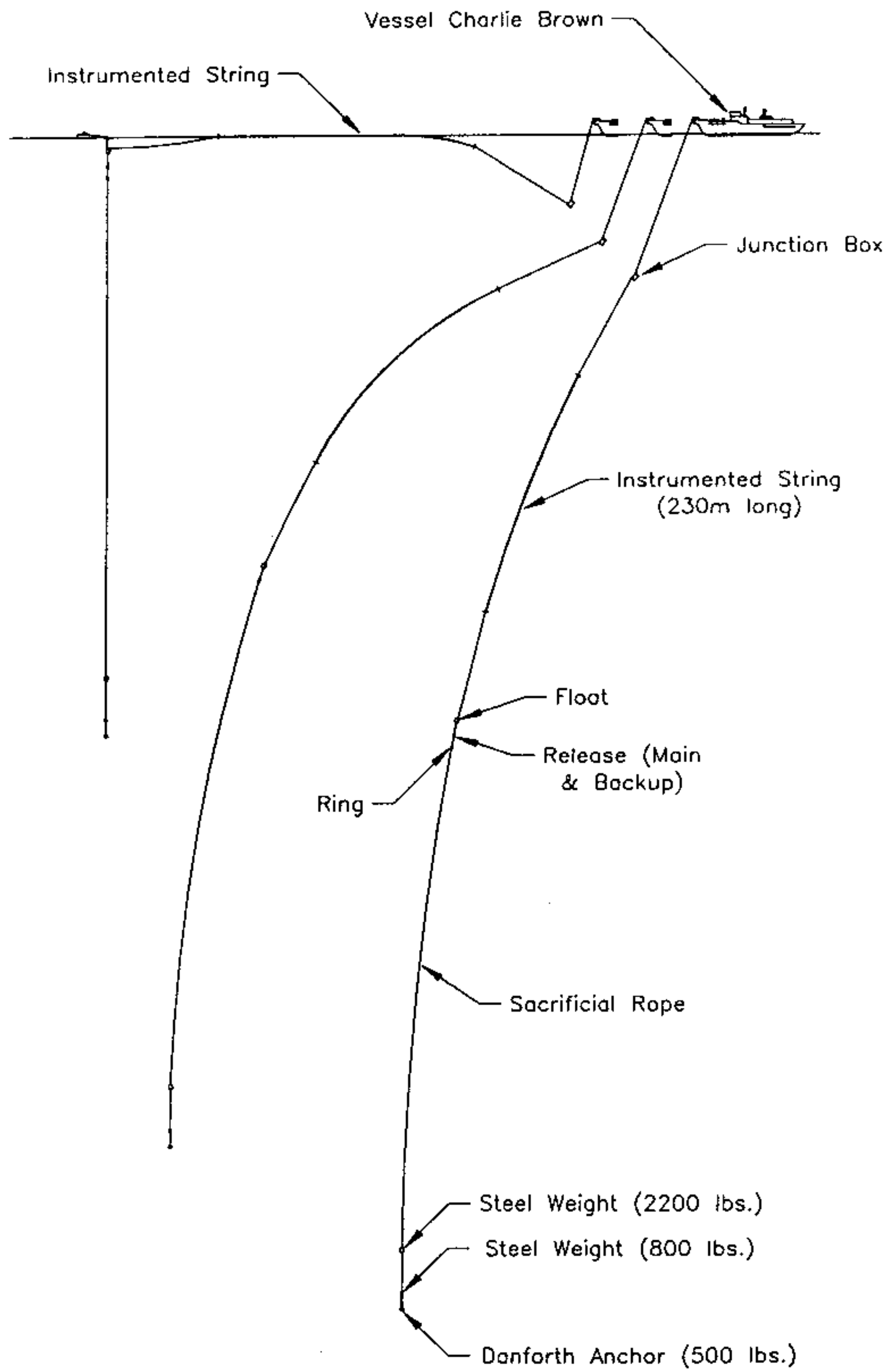
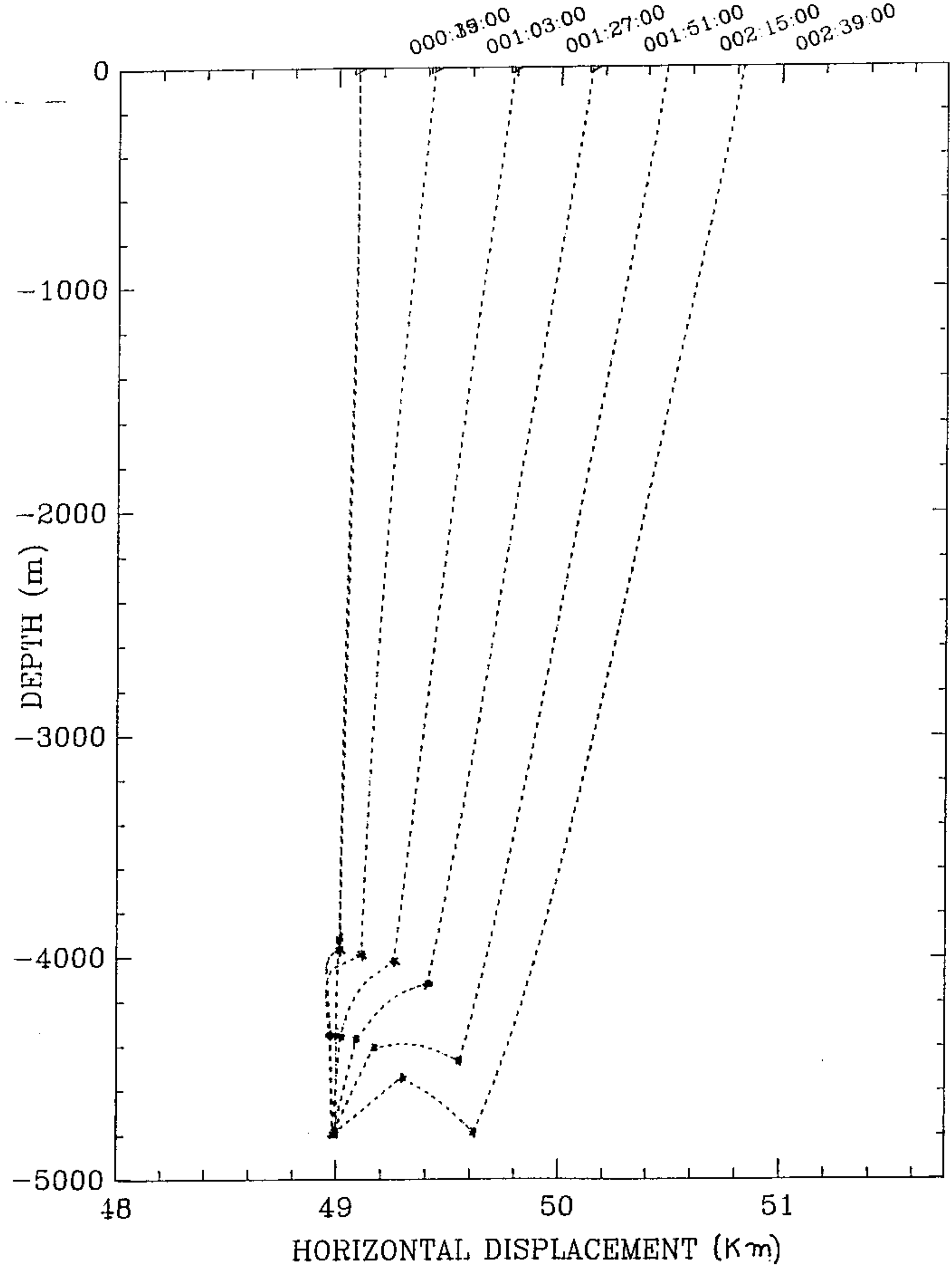
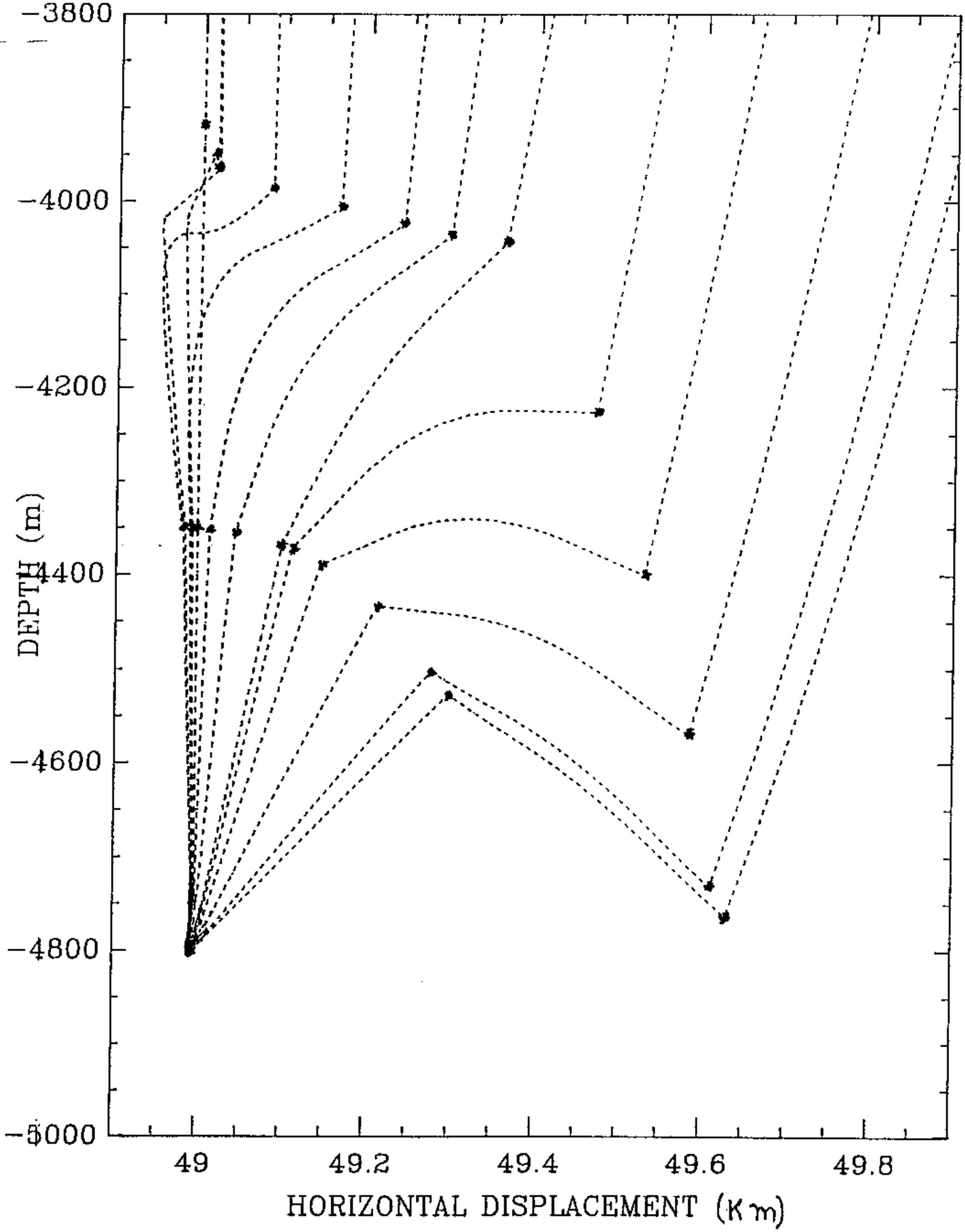

Vessel Charlie Brown
Instrumented String
Junction Box
Instrumented String
(230m long)
Float
Release (Main
& Backup)
Ring
Sacrificial Rope
Steel Weight (2200 lbs.)
Steel Weight (800 lbs.)
Danforth Anchor (500 lbs.)

FIGURE 8



000:15:00
000:39:00
001:03:00
001:27:00
001:51:00
002:15:00
002:39:00
0
-1000
-2000
-3000
-4000
-5000
DEPTH (m)
48
49
50
51
HORIZONTAL DISPLACEMENT (Km)

FIGURE 9



-3800
-4000
-4200
-4400
-4600
-4800
-5000
DEPTH (m)
49
49.2
49.4
49.6
49.8
HORIZONTAL DISPLACEMENT (Km)

FIGURE 10

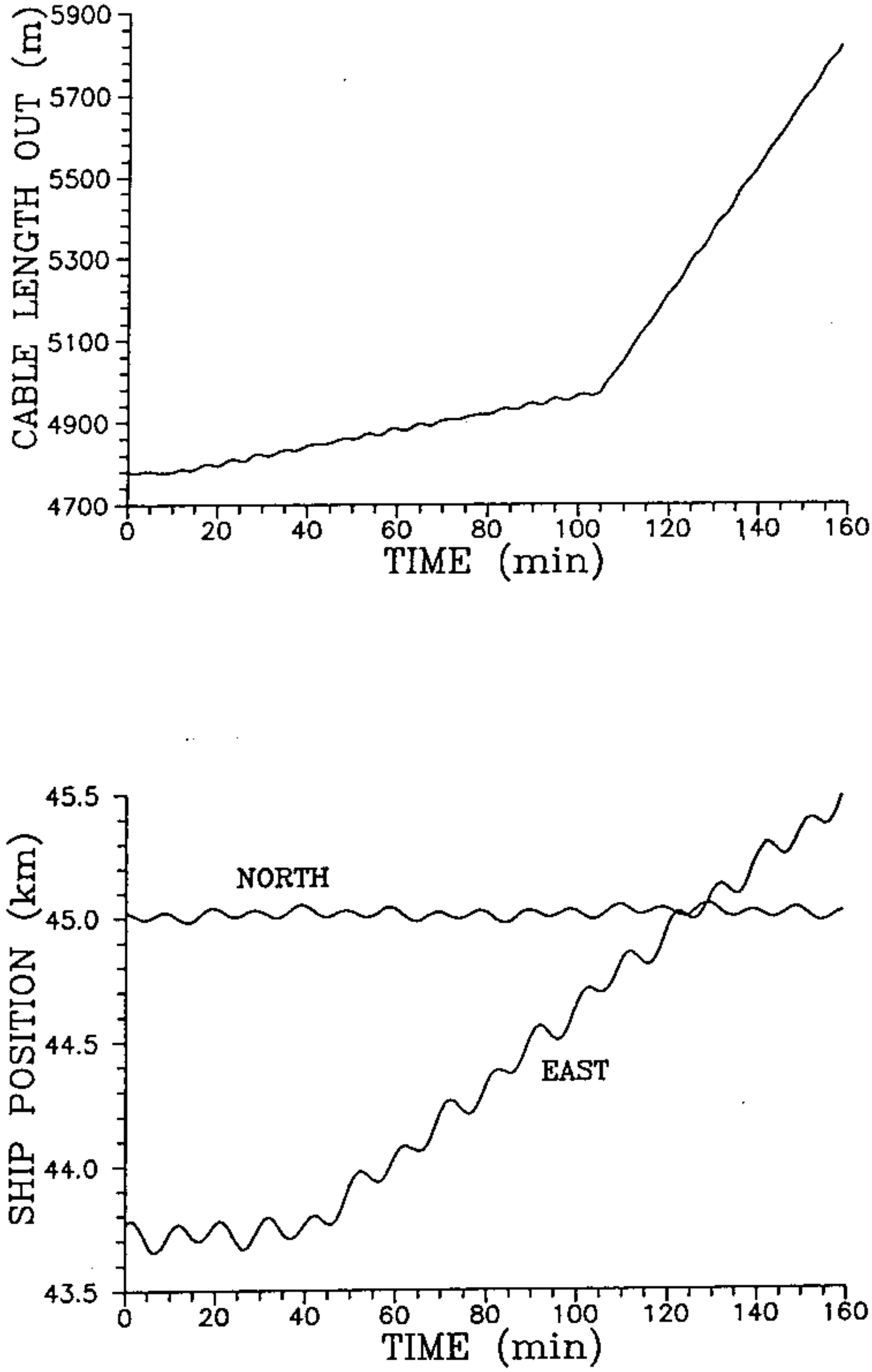


FIGURE 11 CABLE PAYOUT AND SHIP POSITION DURING JUNCTION BOX DEPLOYMENT

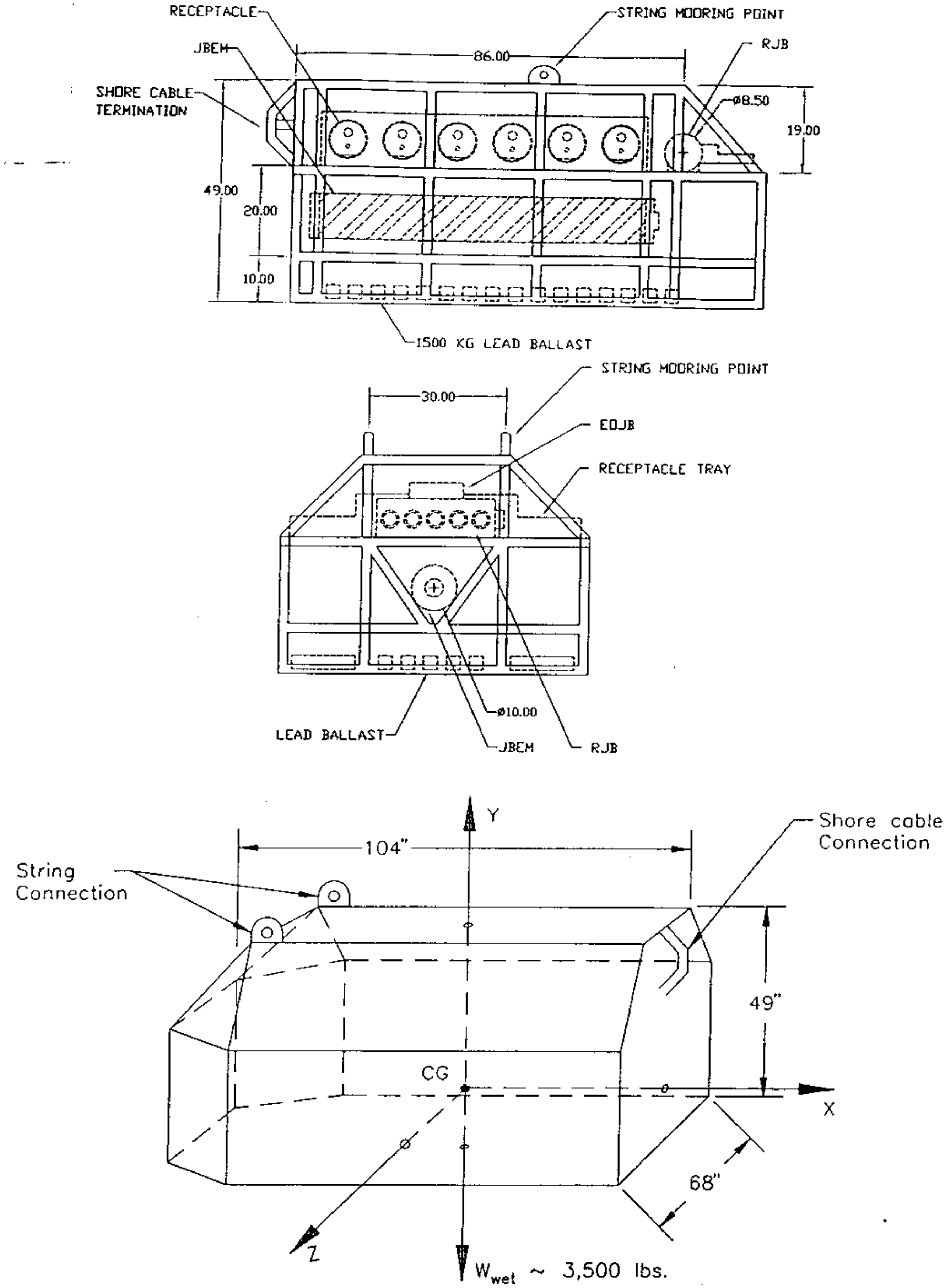
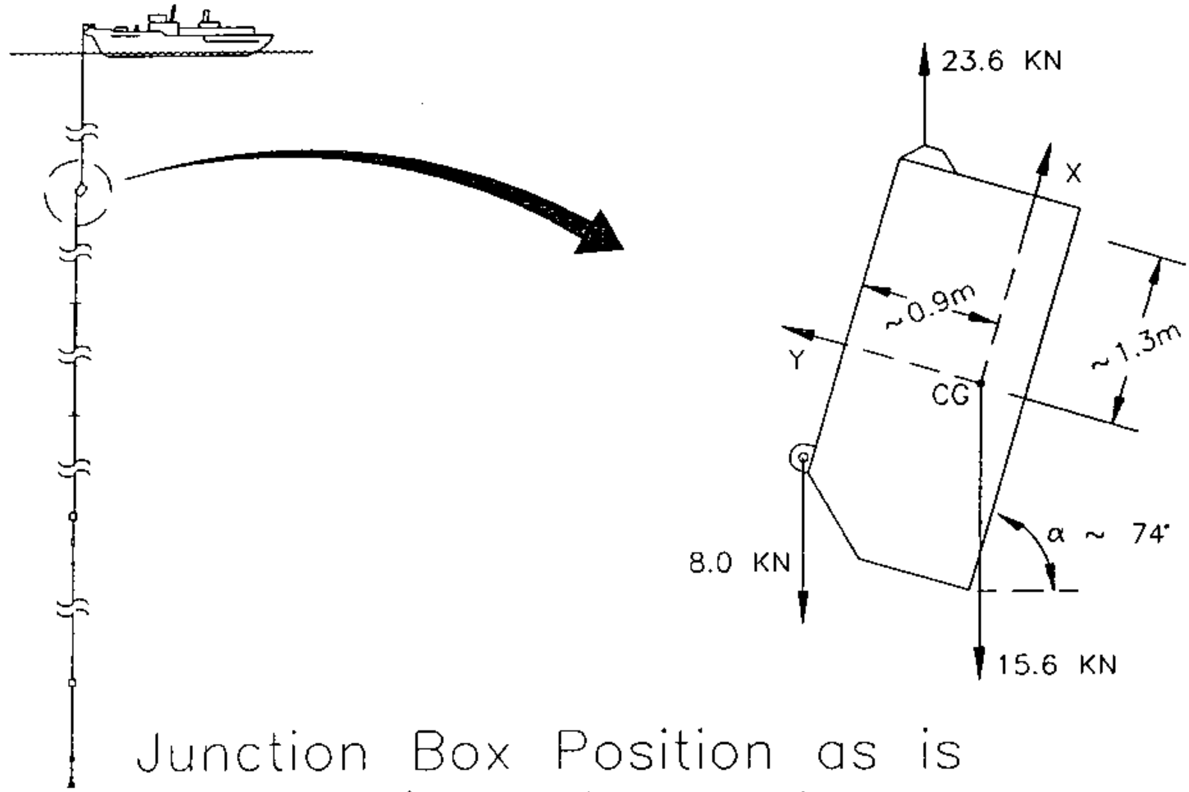
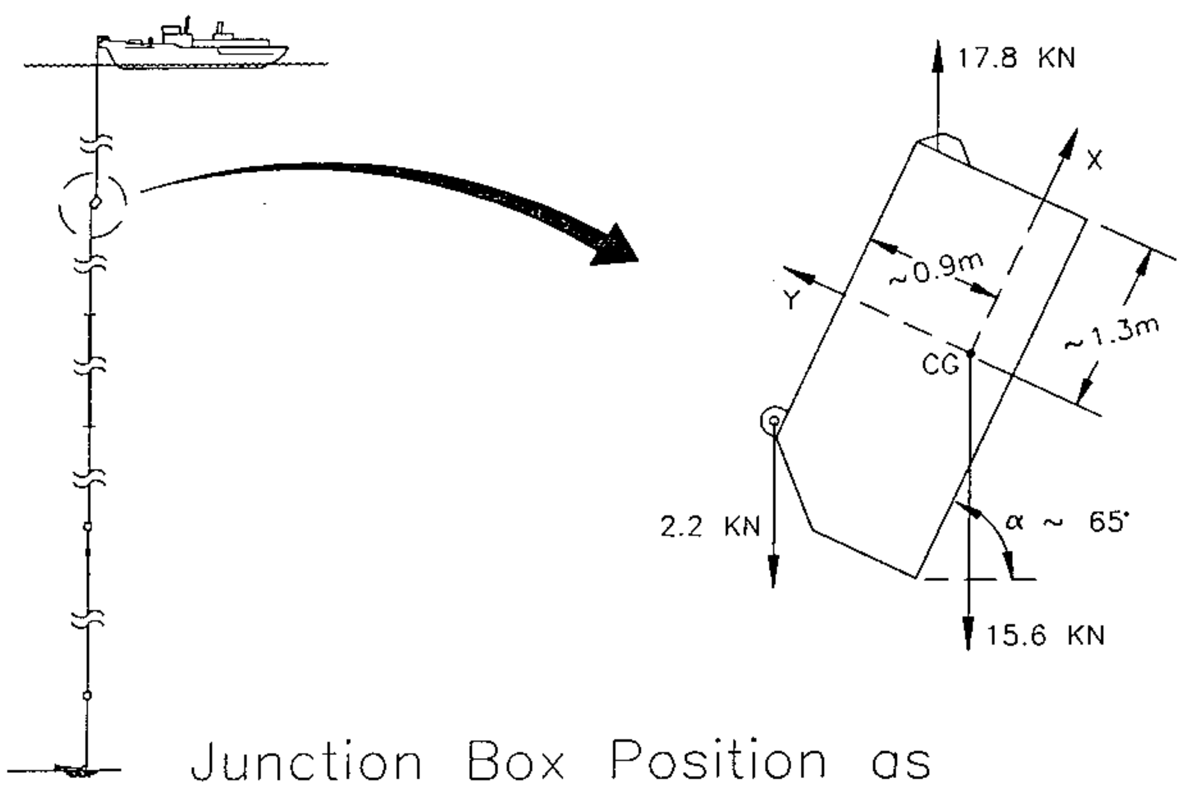


FIGURE 12 Junction Box

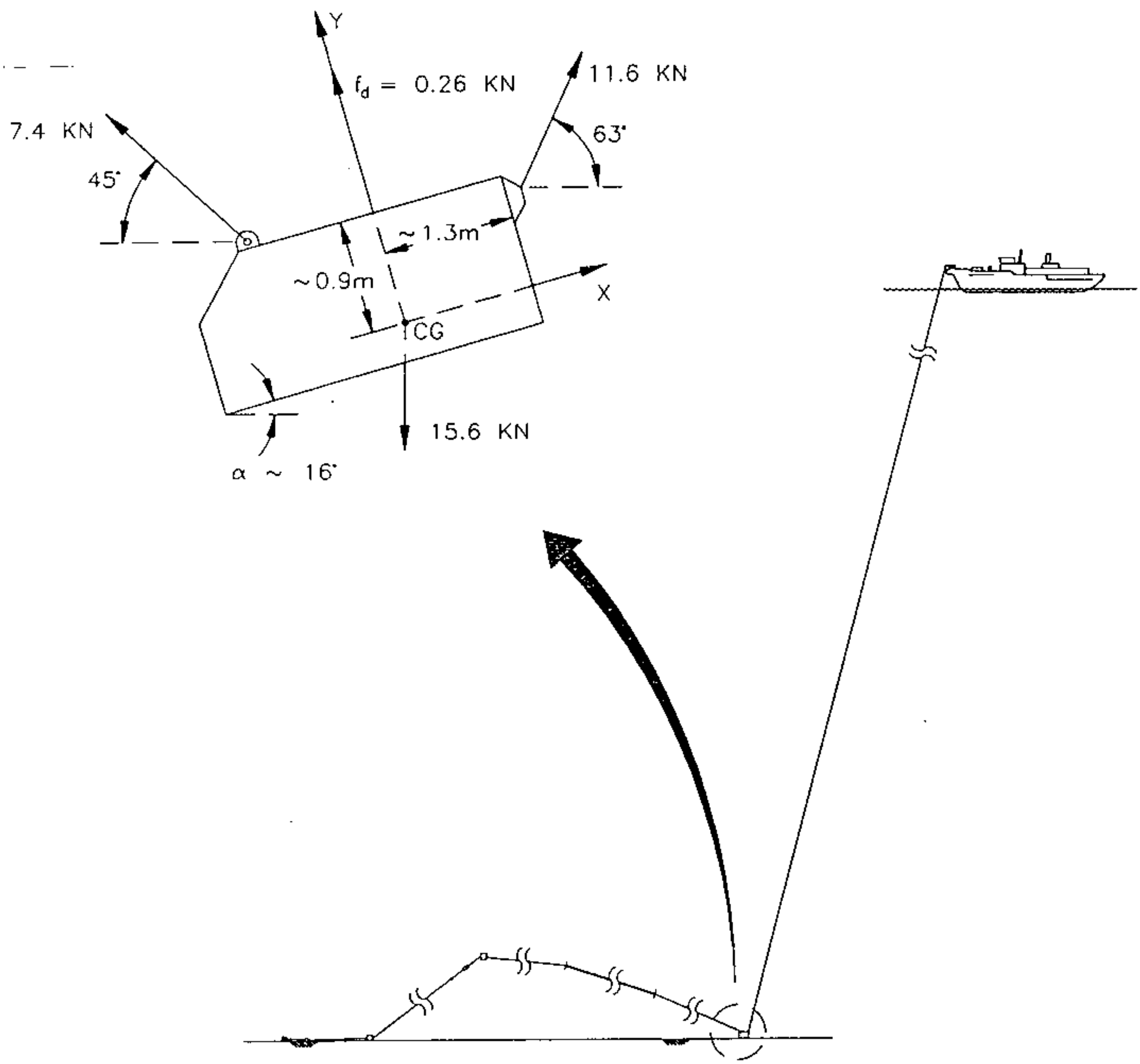


Junction Box Position as is
Vertically Lowered



Junction Box Position as
Anchor Touches Down

FIGURE 13



Junction Box Position as
it Touches Down

FIGURE 14

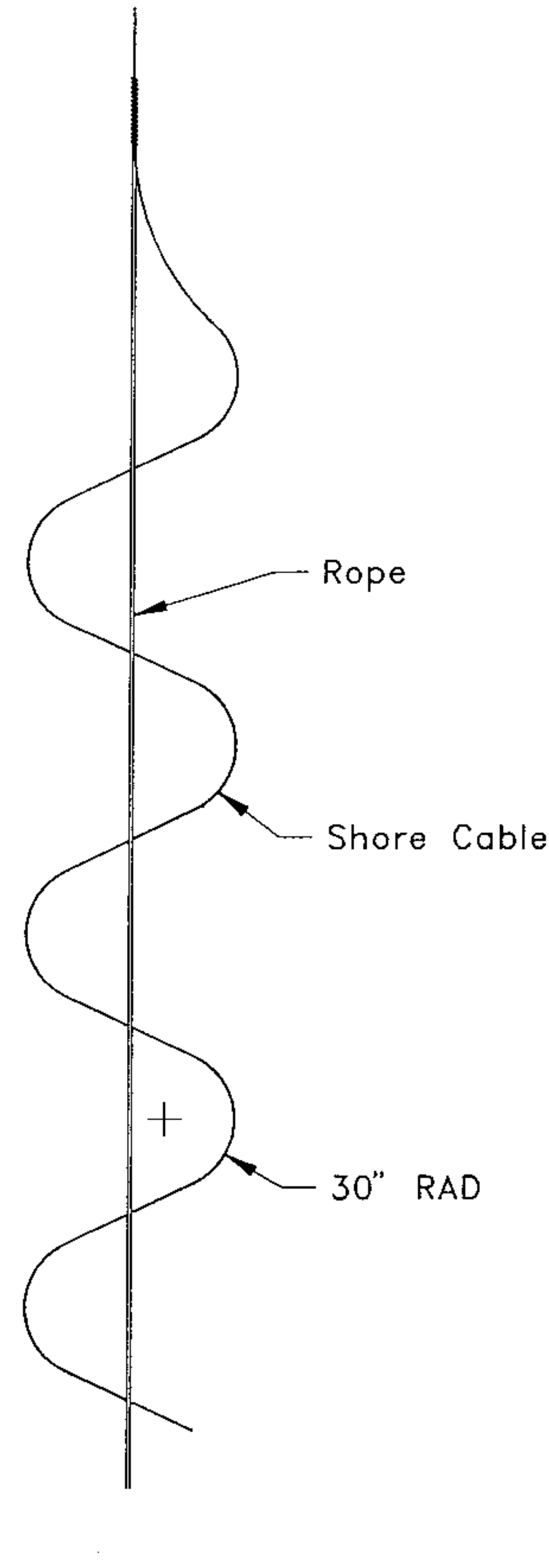


FIGURE 15

APPENDIX 1:
Update on Ship Logistics

Peter Gorham
University of Hawaii DUMAND Group

TABLE 1

M/V INDEPENDENCE

GENERAL SPECIFICATIONS

OWNER:	U.S. GOVERNMENT NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME, CA
OPERATOR:	WESTERN INSTRUMENT CORP. 4050 MARKET STREET VENTURA, CA
OPERATED AS:	MULTI-PURPOSE MOTOR VESSEL
HOME PORT:	PORT HUENEME, CA
LENGTH (LOA):	200 FEET
LENGTH (WL):	182 FEET
BEAM:	40 FEET
DRAFT:	13.5 FEET
DISPLACEMENT:	1798 LT
MAXIMUM ENDURANCE:	30 DAYS
SPEED (MAXIMUM):	13 KNOTS
SPEED (CRUISE):	11 KNOTS
RANGE (MAX SPEED):	7800 NAUTICAL MILES
RANGE (CRUISE SPEED):	8500 NAUTICAL MILES
YEAR / PLACE BUILT:	1985 / MOSS POINT, MISS
CREW:	11
BERTHING:	27 (INCLUDING CREW)

Availability of Cable Lay Ships

The proposed plan in this document has been specifically tailored to the details of the Charles Brown, the ATT vessel which has for some time been envisioned as the primary vessel for the deployment of the junction box and the laying of the shore cable. This is primarily because of its cable laying capabilities. However, recent news, received after the preparation of the other two documents in this package, indicates that the probability is low for the Charles Brown to be present in Hawaii at the time required for the initial DUMAND deployment operations, since it is likely to be transferred to Atlantic operations in mid-1993. At present, ATT has no plan to station a cable-lay vessel full-time in Honolulu during 1993; thus we are forced to plan on other possibilities. For the purposes of this discussion, we have adopted a plan which provides us with firmer ground for the planning of the deployment logistics.

Because the proposed operation involves a complex instrument deployment as well as a cable lay, the ideal ship is one that combines both cable laying capacity, such as suitable linear cable engines and cable trays, with good station-keeping ability and extensive deck equipment for handling of the deployment of complex instrument arrays. A ship such as the ATT C/S Global Explorer, which is capable of dynamic positioning (DP) as well as having cable capacity for transoceanic lays, would be ideal; however, the cost of such a vessel (of order $60K/day) is prohibitive were it available. In addition, the cable lay portion of our deployment is very short compared to the standard deep ocean cable lays for which these ships are designed, and more modest cable storage and handling capabilities can be quite adequate.

The M/V Independence

Because of the uncertainty in the availability of cable lay ships, we have instead opted to schedule our deployment operations with a vessel for which we can procure a more definite committment, and which we feel will be well-suited to the job. We have chosen to adapt a highly-recommended DP vessel, the M/V Independence (Port Hueneme, CA), to our deployment and cable lay needs. The vessel has participated in successful cable-lay operations in the past, notably one recently involving a cable very similar in construction and length to the DUMAND cable. This cable, designed also by the DUMAND cable designer G. Wilkins, contained four single-mode fibers and was deployed with a series of oceanographic instruments along its length off the Pacific Northwest Coast. In addition to this operation which was very similar in scope to our proposed deployment, the Independence has participated in about a half-dozen other operations involving moderate to long lays of fiber optic cable, including several which also involved fairly complex instrument packages. Tables 1,2 and Figures 1,2 in this appendix are provided by the master of the Independence as documentation for the capabilities of the vessel.

The deck layout of the Independence is shown in Figure 3, including a preliminary scheme for the layout of the deck equipment that will be required for the proposed deployment operation. This includes a large TSE Pengo cable engine, used for the main cable lowering and the cable laying operations; a back-tensioning cable engine used to tail the main cable engine; a cable pan; a 24 ft van containing the string; and the junction box. The ships gear available includes a 22 ton crane which can support all of the deployment loads during the early stages of the operation (before the cable hanging weight becomes dominant). In addition, a 25 ton towing winch is available to provide backup support for over-the- side operations should it be required. The smaller 1 ton crane on the aft end of the O1 deck is available to support the cable panning operations. Two 5000 lb capstans port and starboard amid the after deck are also available for tagging operations. Not shown in the deck plan here is a detachable A-frame which can provide a span of approximately 5 m above the stern for a large deployment sheave, if a skid-plate is deemed to be inadequate.

Inquiries at the time of writing of this document are in progress to determine whether the Advanced Tethered Vehicle (an unmanned deep submergence vehicle which can make the string interconnects for us) could be brought to Hawaii with the Independence. The Independence has been verified to be capable of supporting the ATV on its afterdeck, although it could probably not support both a string deployment and ATV deployment simultaneously. However, this option presents the most complete possibility yet considered for DUMAND Phase I deployment: the possibility of a single ship being the support ship for all three of the major deployment steps: cable/JBOX/string 1; followed by strings 2 and 3; followed by a string interconnection operation.

In addition to the tables and figures included in this appendix, we also include after Figure 3, a resume of cable-lay operations supported by the Independence.

Table and Figure Captions

Figure 1

Side view of the M/V Independence.

Table 1

Independence general specifications.

Table 2

Independence Deck specifications.

Figure 2

Independence inboard side profile.

Figure 3

Plan view of Independence afterdeck, showing block placement for DUMAND deployment gear.

Resume

Documentation of cable lay operations supported by the Independence.

TABLE 2

M/V INDEPENDENCE

DECK CHARACTERISTICS

WORK DECK AREA:	3200 SQ. FT.
MAXIMUM DECK CARGO:	383 L TONS
DECK LOAD CAPACITY:	STIFFENED - 600 LBS/SQ. FT. UNSTIFFENED - 450 LBS/SQ. FT.
UTILITY HOOKUPS:	480 VAC, 225 AMP, 3 PHASE 480 VAC, 70 AMP, 3 PHASE 480 VAC, 20 AMP, 3 PHASE 208 VAC, 60 AMP, 3 PHASE 208 VAC, 30 AMP, 3 PHASE
RECESSED TIE DOWNS:	66 THREADED BOLT HOLES (1"-8)
CRANE:	22 TON MAX LIFT (SEE CAPACITY CHART) TELESCOPING BOOM (65 FT) - ⅝ X 200 FT LIFT CABLE 1 TON SHIP STORE CRANE 0-1 DECK
TOW WINCH:	50,000 LBS. MAX LOAD, 2000 FT. X 1 - 3/16" CABLE
TOWING PINS:	HYD - NORMAN PINS
CAPSTANS:	MAIN DECK, PORT/STBD (5000 LBS)
ANCHOR WINDLASS:	DOUBLE WILDCAT, DOUBLE CATHEAD
ENCLOSED LAB AREA:	400 SQ. FT
SERVICE PORTS:	HYD - 6GPM @2,300PSI 10GPM @2,300PSI AIR - 125PSI @400CFM 125PSI @184CFM WATER - FRESH/SEA
WORK BOATS:	17 FT. INFLATABLE (55HP) 18 FT. BOSTON WHALER (TWIN 60 HP) 17 FT. RIGID HULL INFLATABLE (90 HP)

M/V INDEPENDENCE

UNITED STATES NAVY
NAVAL CIVIL ENGINEERING LABORATORY

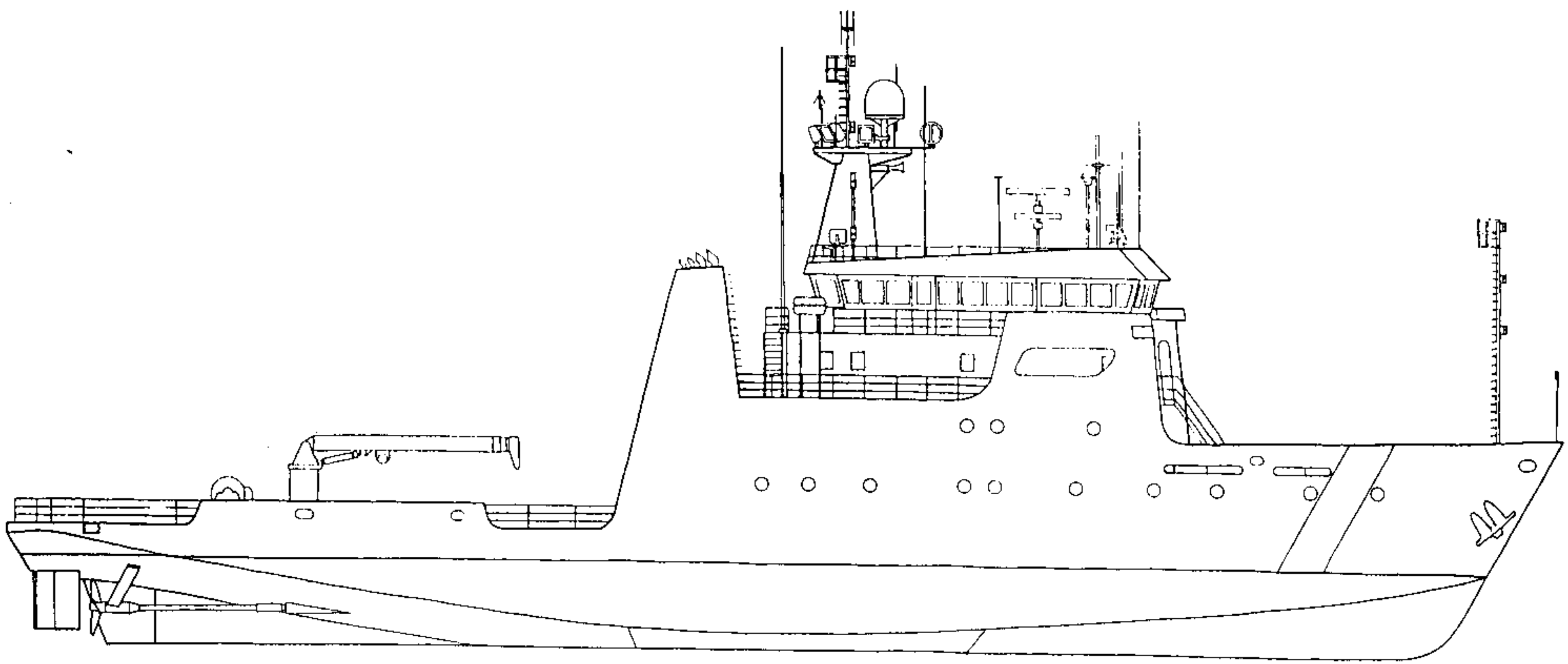
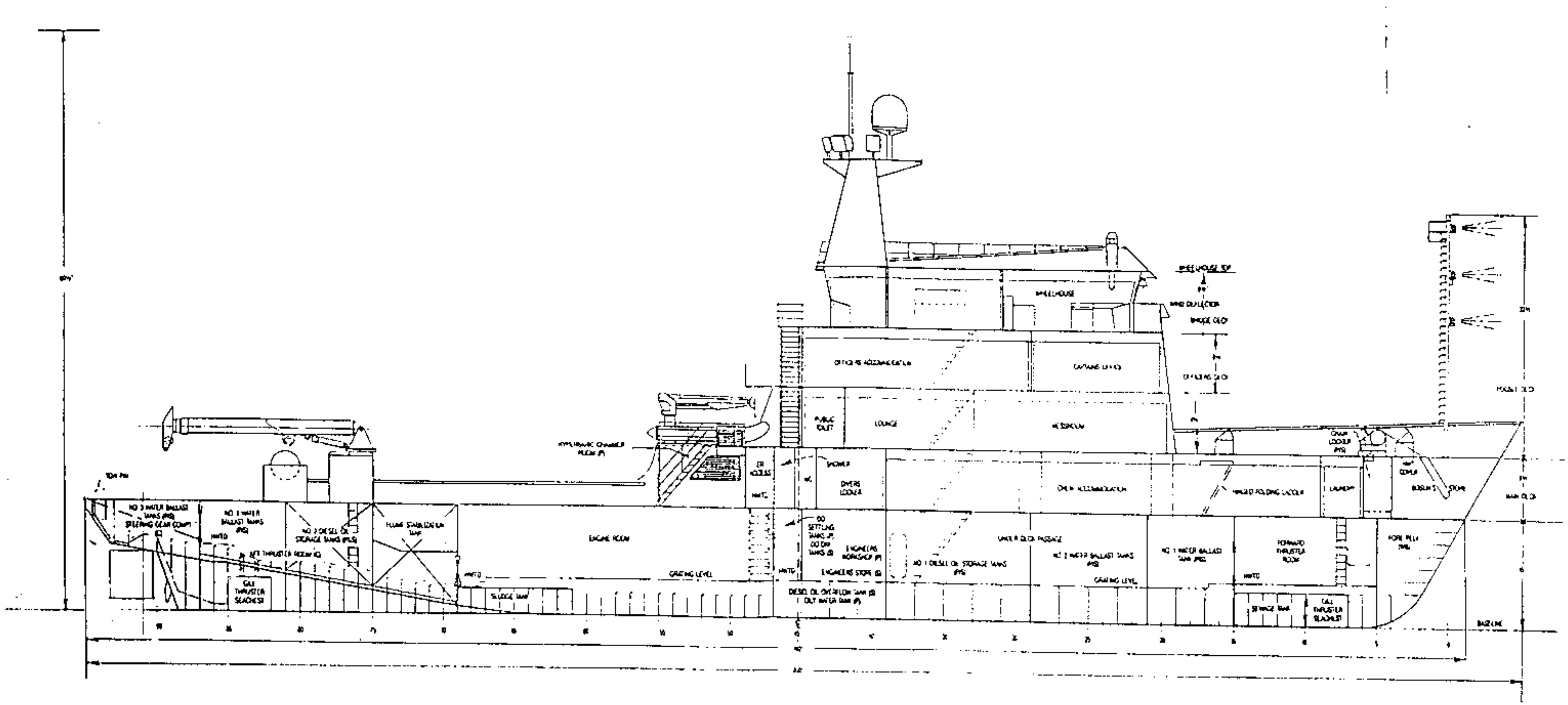


FIGURE 1



INBOARD PROFILE

FIGURE 2

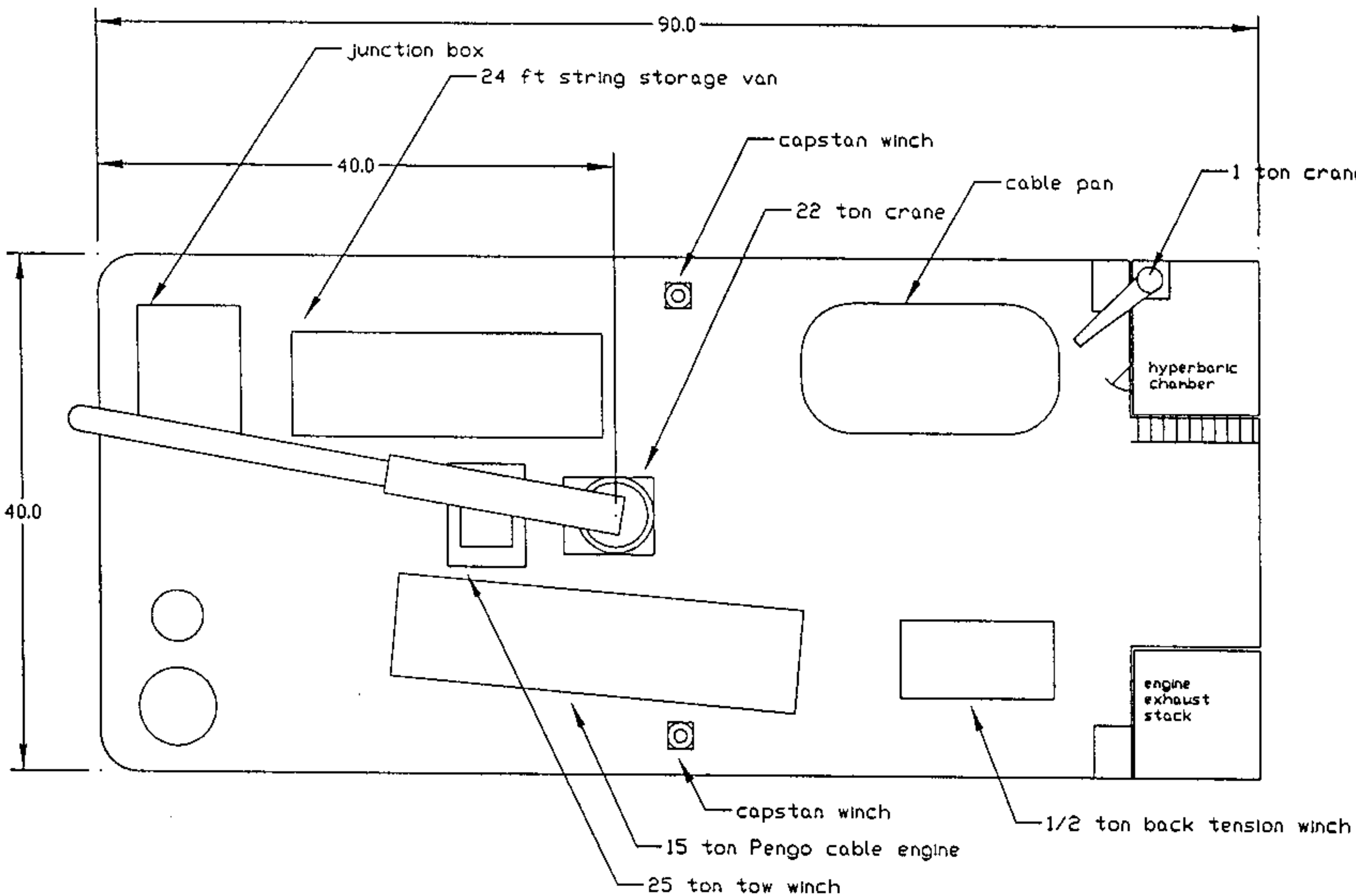

90.0
junction box
24 ft string storage van
40.0
capstan winch
22 ton crane
cable pan
1 ton crane
hyperbaric chamber
engine exhaust stack
40.0
capstan winch
15 ton Pengo cable engine
25 ton tow winch
1/2 ton back tension winch

FIGURE 3

CABLE LAY RESUME

18 Dec 1992

To: Mr Pete Gorham
University of Hawaii

From: Mark H. Wood
Program Manager, M/V INDEPENDENCE
Western Instrument Corporation

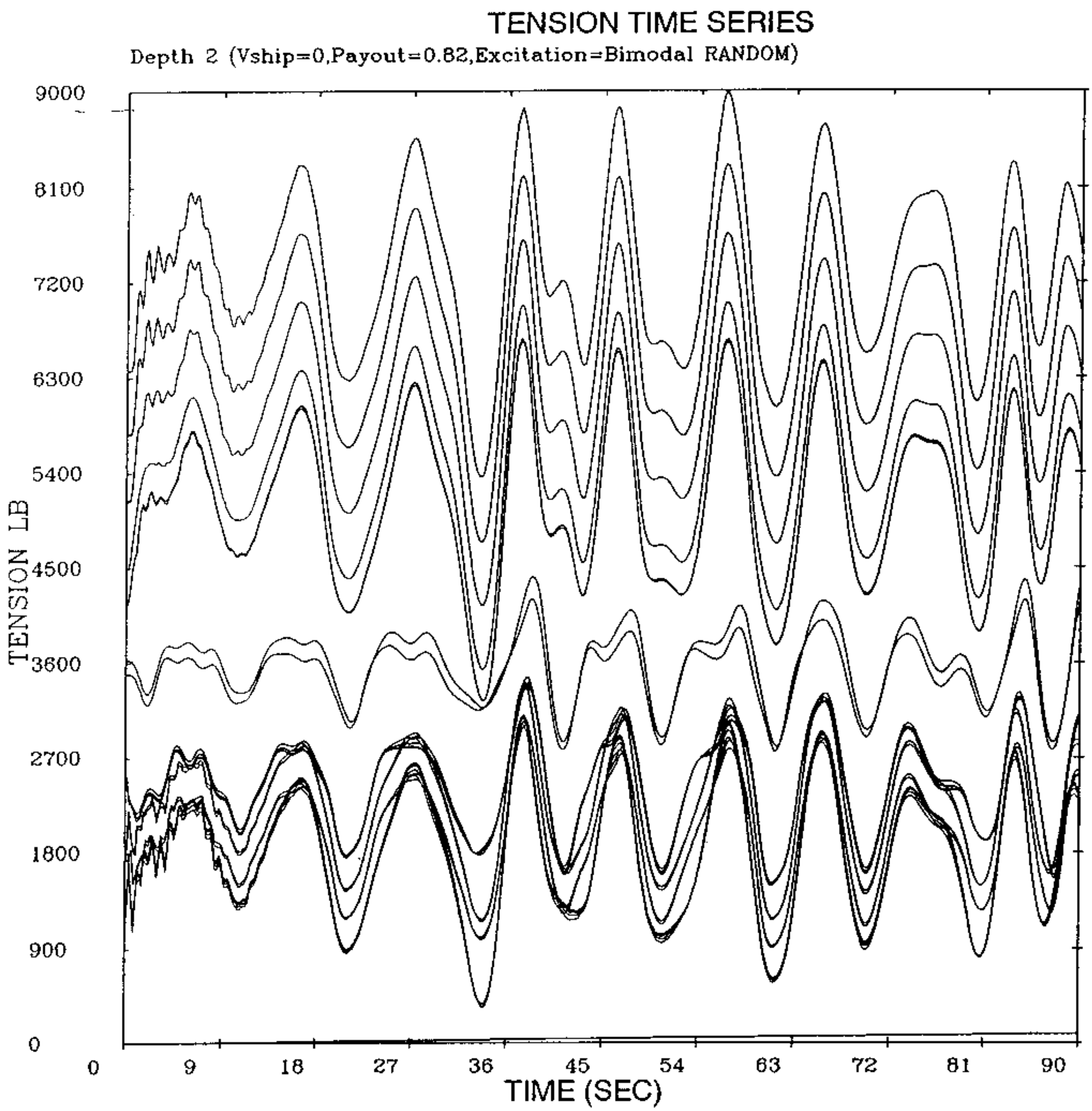
CABLE AND ARRAY OPERATIONS CONDUCTED ABOARD THE M/V INDEPENDENCE

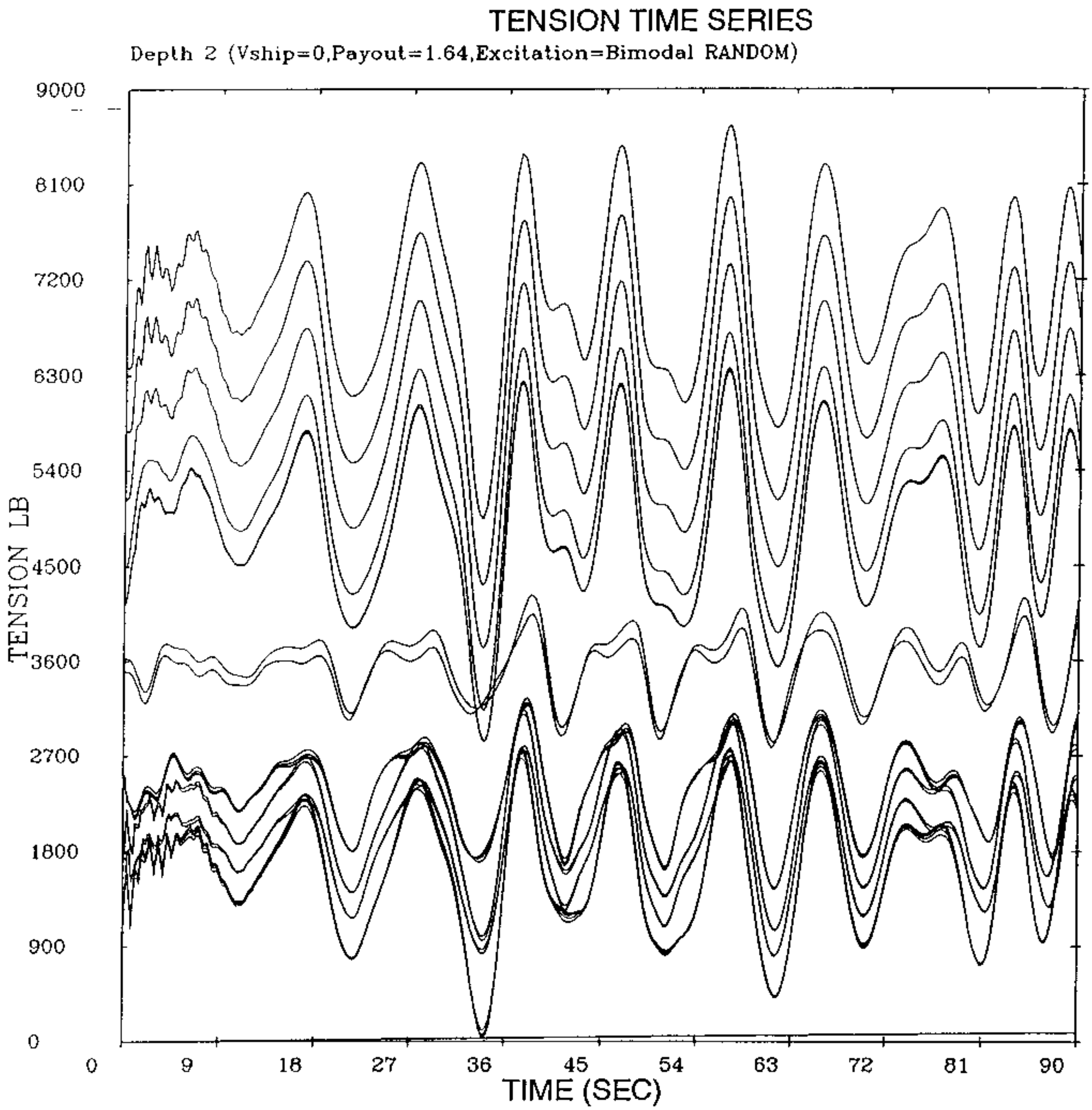
The focus on the INDEPENDENCE operations and her support is primarily the installation and operation of experimental equipment. The engineering and technical support to the experiment must not become a major developmental effort, and thus a risk to success, in and of itself. Through applied technical capability and experience the INDEPENDENCE and her support offers the University a program risk reduction capability unmatched in the industry. The INDEPENDENCE and her support resources contain not only the corporate memory of extensive research and development catered specifically to your needs, but also the skills and innovative talents of technical staff from other high technology and ocean related work. The result is a broad base of ocean-engineering experience to apply practical solutions to operational support and innovations garnered from other parts of the industry where there is a discernable payoff.

The INDEPENDENCE and her support staff recognize the charecteristics of well-managed risk and incorporates this strategy in technical development procedures. For instance, the INDEPENDENCE and her support group often uses advanced analysis as the foundation for design, innovating first in theory and then in development. Mastery of risk-reduction approach through incrumental innovation is the hallmark of the INDEPENDENCE and her support group. This will become apparent after reviewing a brief summary of some programs conducted from the INDEPENDENCE. In addition, if you desire, a more complete presentation and slide show is available.

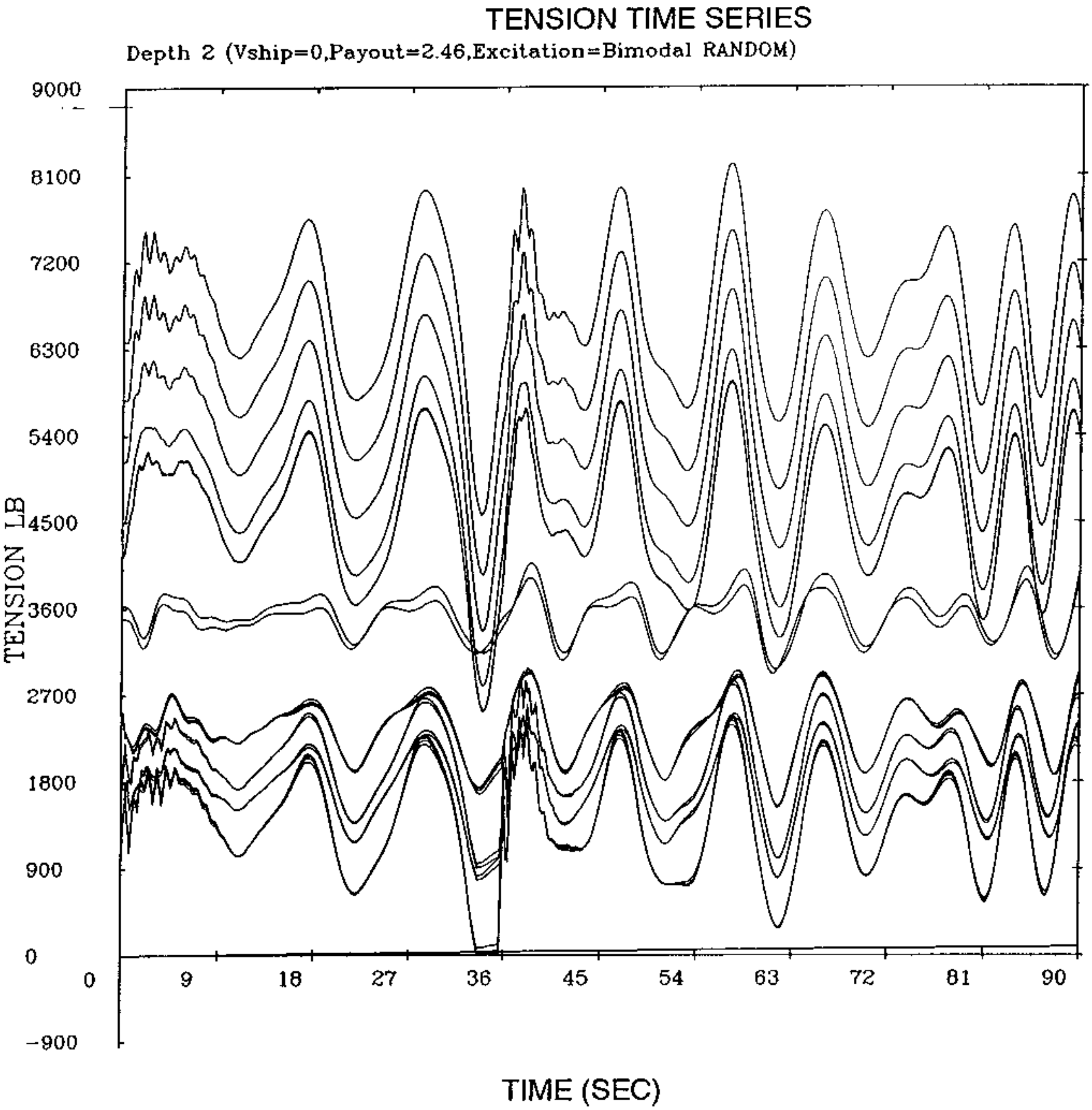
PROGRAM ACRONYM: PASS I & PASS II

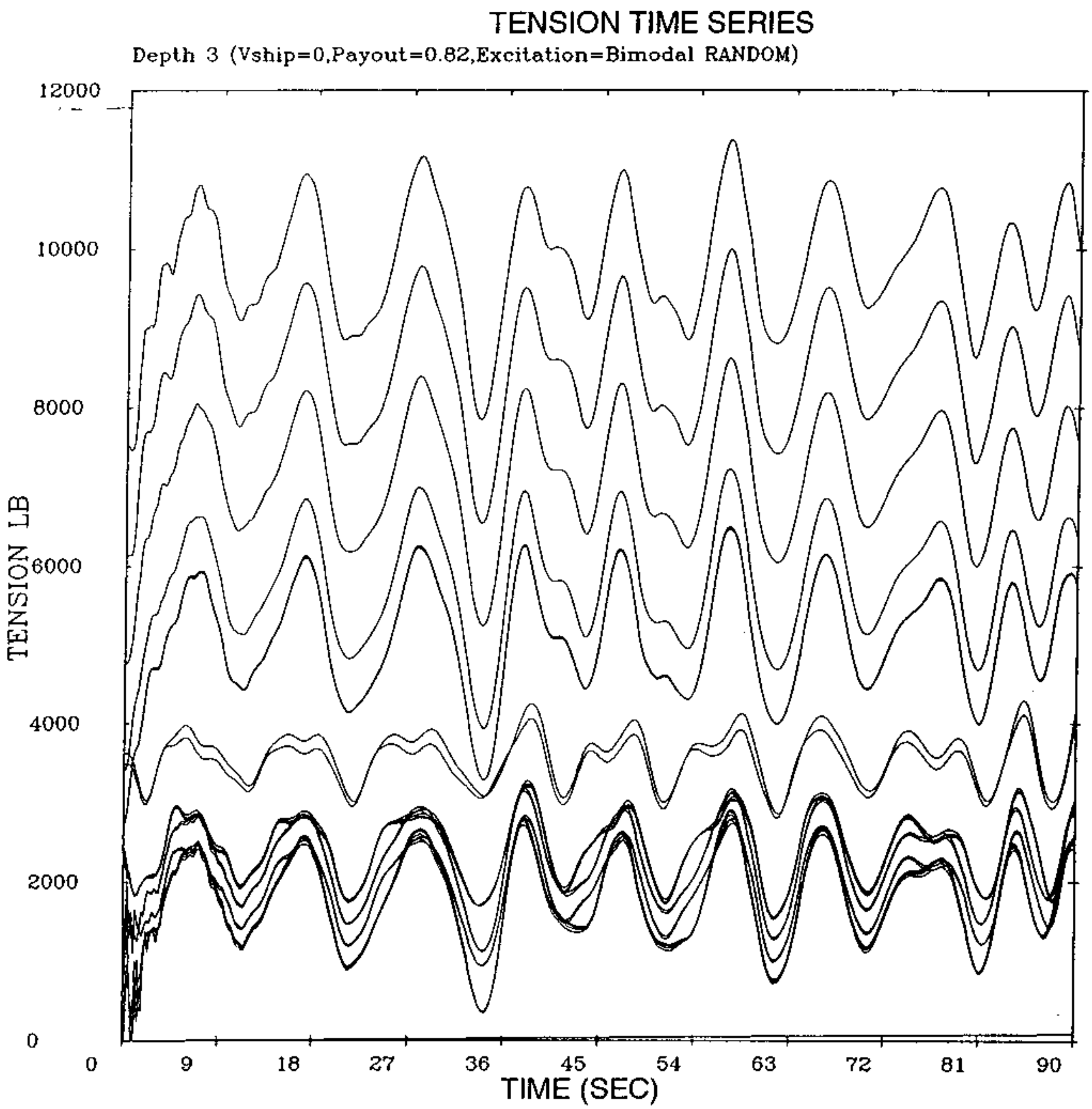
During this multi-phased project the Independence was tasked to place and recover sensor systems and cable along pre-plotted positions and routing at velocities under 1.5 kts. Each system was approximately 3.5 to 4 nautical miles long (shore linked cable being 3 to 3.5 miles plus a .5 to 1.0 mile sensor). The deployment site was along a high traffic area and currents ranged from 0-4 kts.. The placement of the sensor systems was critical to the operation as well as, orientation, and slack measurements.

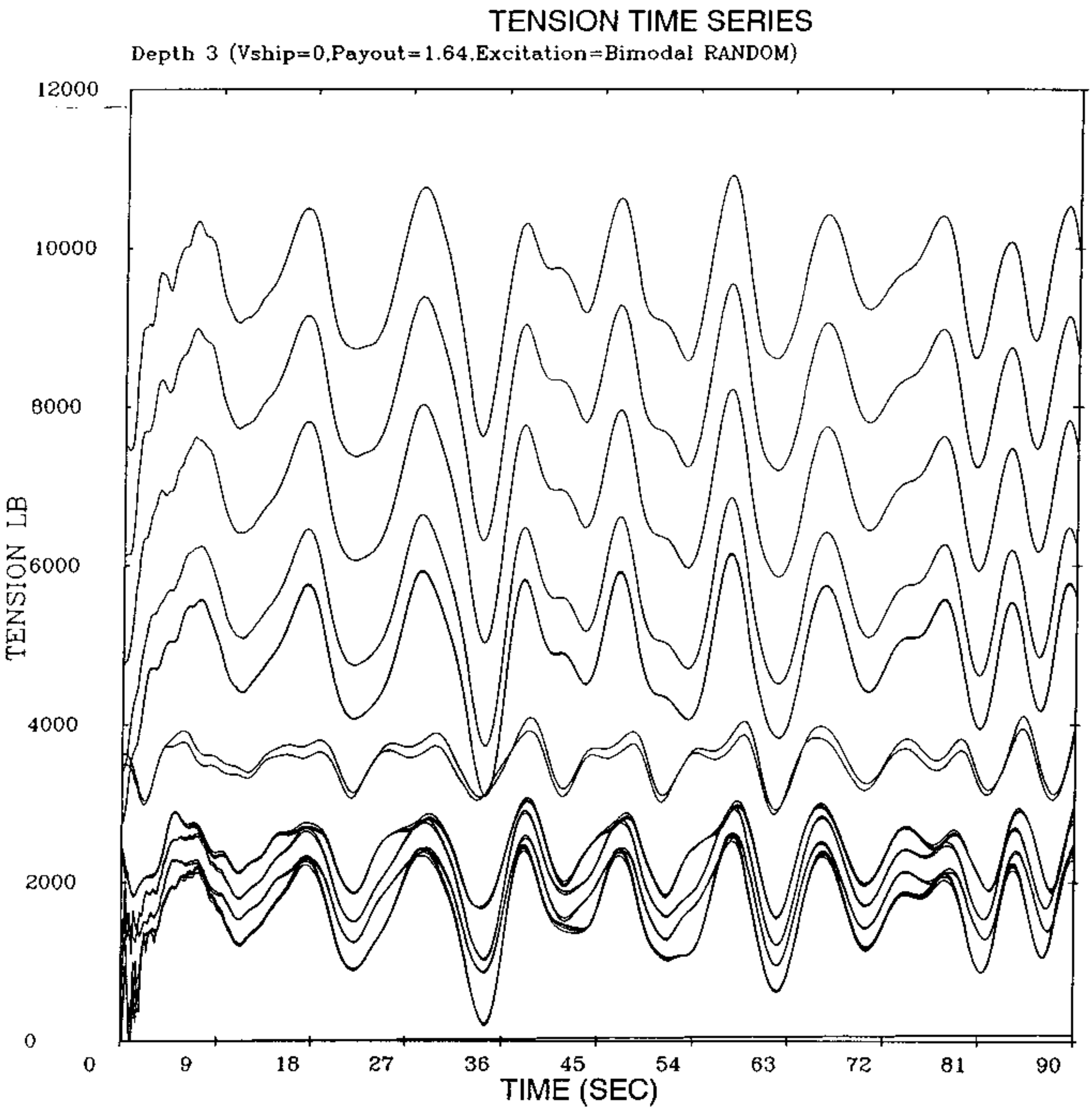

TENSION TIME SERIES
Depth 2 (Vship=0,Payout=0.82,Excitation=Bimodal RANDOM)
TENSION LB
9000
8100
7200
6300
5400
4500
3600
2700
1800
900
0
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)

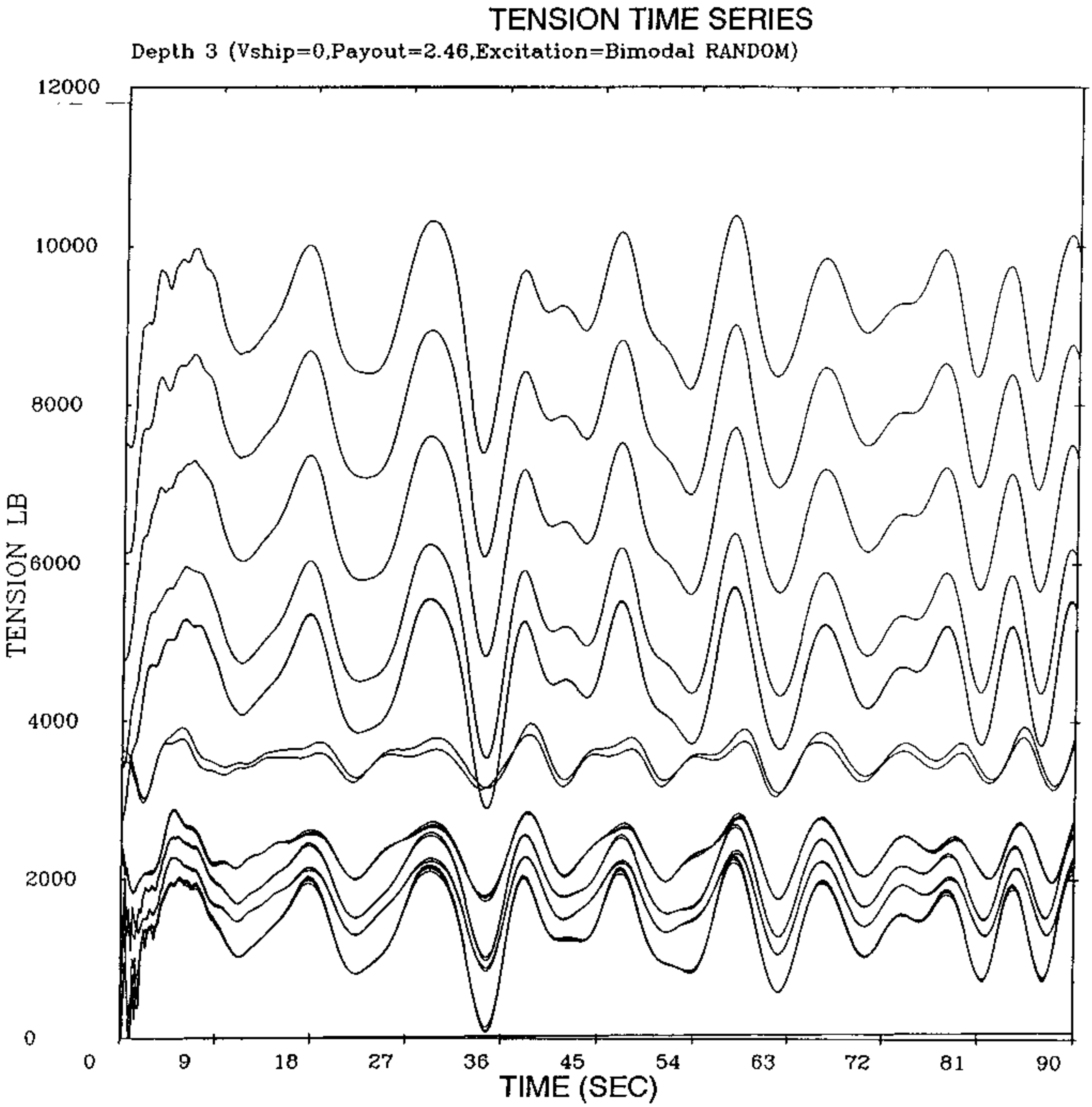


TENSION TIME SERIES
Depth 2 (Vship=0,Payout=1.64,Excitation=Bimodal RANDOM)
TENSION LB
9000
8100
7200
6300
5400
4500
3600
2700
1800
900
0
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)


TENSION TIME SERIES
Depth 2 (Vship=0,Payout=2.46,Excitation=Bimodal RANDOM)
9000
8100
7200
6300
5400
4500
3600
2700
1800
900
0
-900
TENSION LB
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)


TENSION TIME SERIES
Depth 3 (Vship=0,Payout=0.82,Excitation=Bimodal RANDOM)
TENSION LB
12000
10000
8000
6000
4000
2000
0
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)


TENSION TIME SERIES
Depth 3 (Vship=0,Payout=1.64,Excitation=Bimodal RANDOM)
TENSION LB
12000
10000
8000
6000
4000
2000
0
TIME (SEC)
0
9
18
27
36
45
54
63
72
81
90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Depth 3 (Vship=0,Payout=2.46,Excitation=Bimodal RANDOM)
TENSION LB
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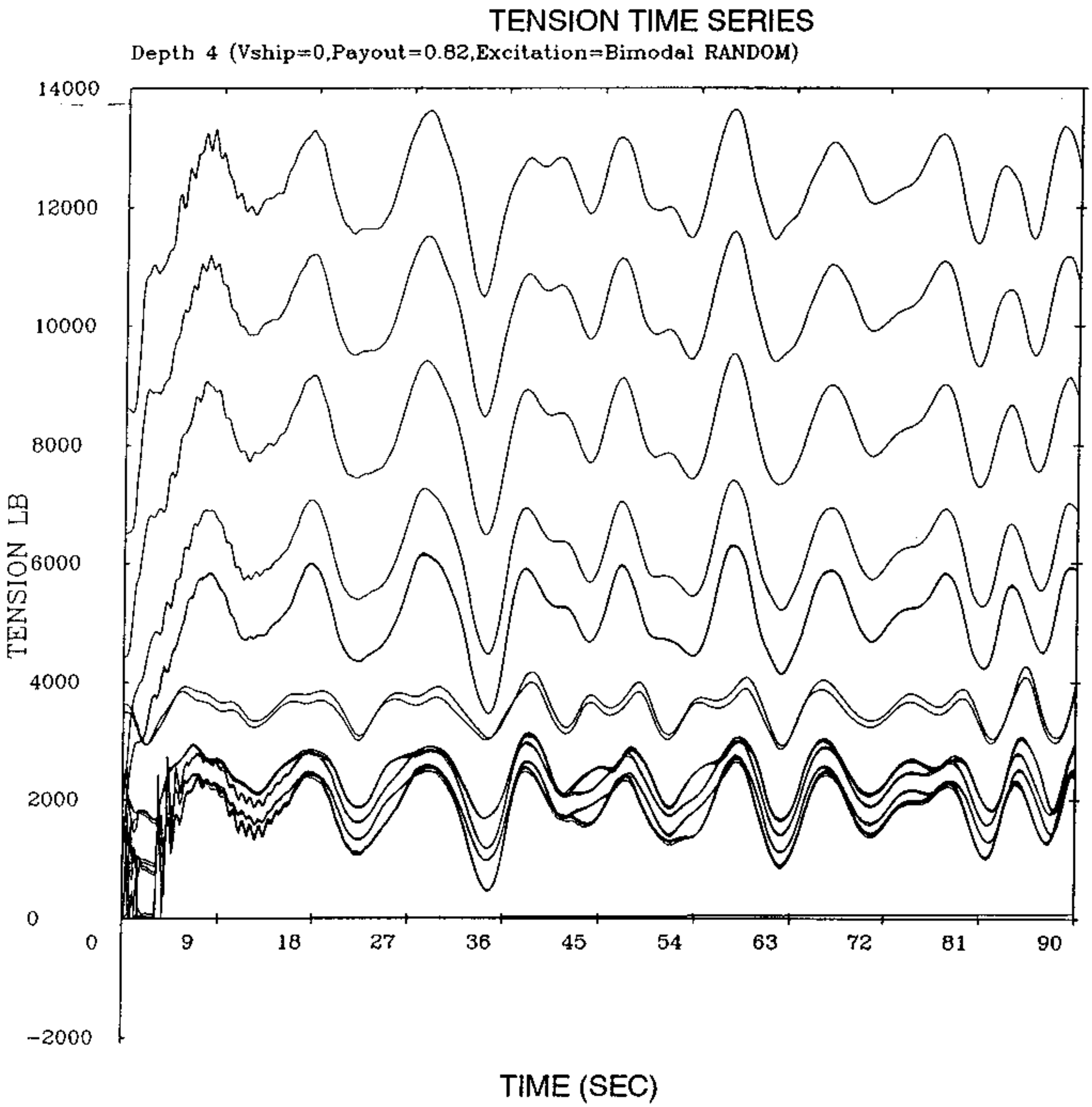
10000
8000
6000
4000
2000
0
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)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Depth 4 (Vship=0,Payout=0.82,Excitation=Bimodal RANDOM)
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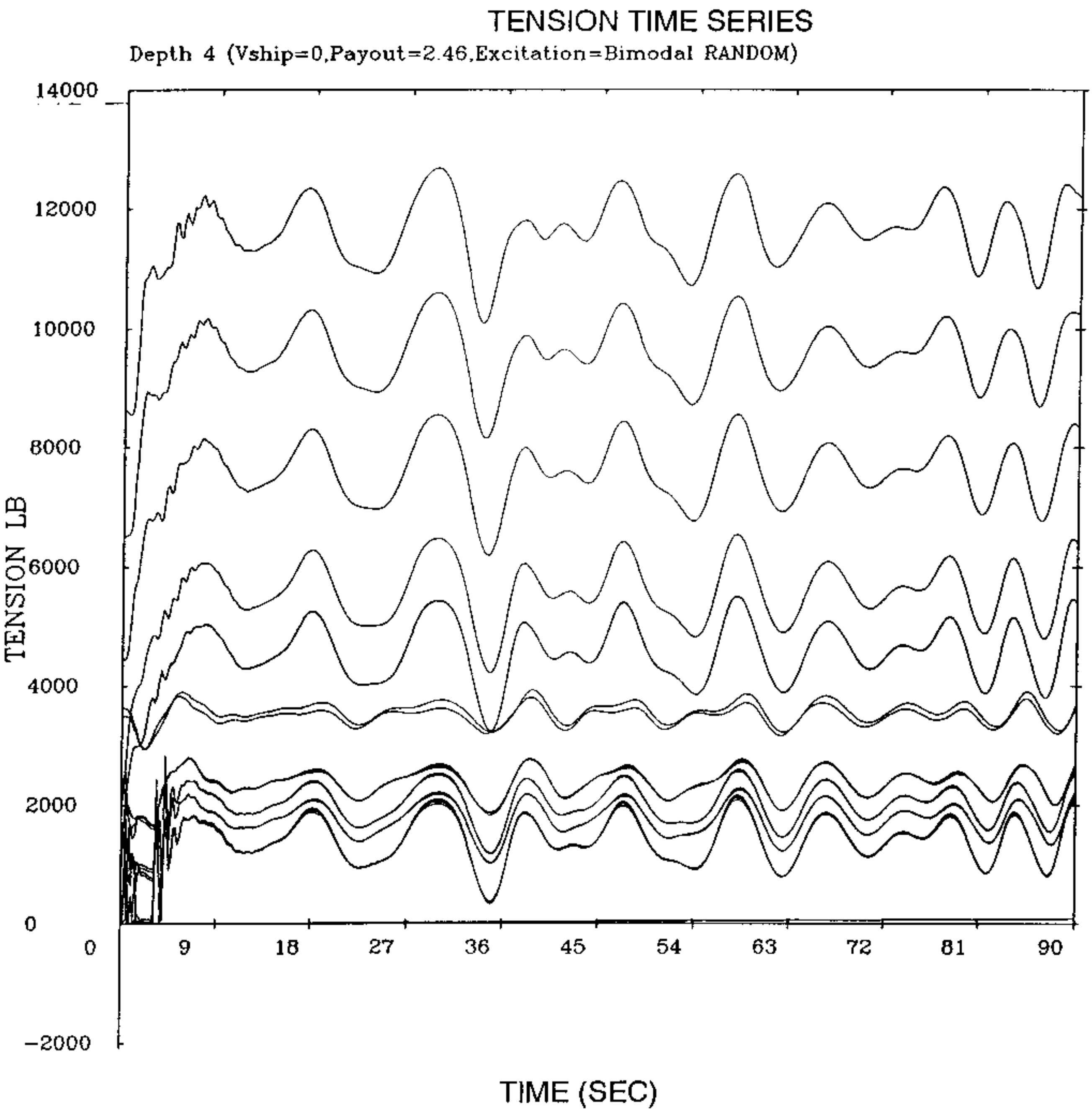
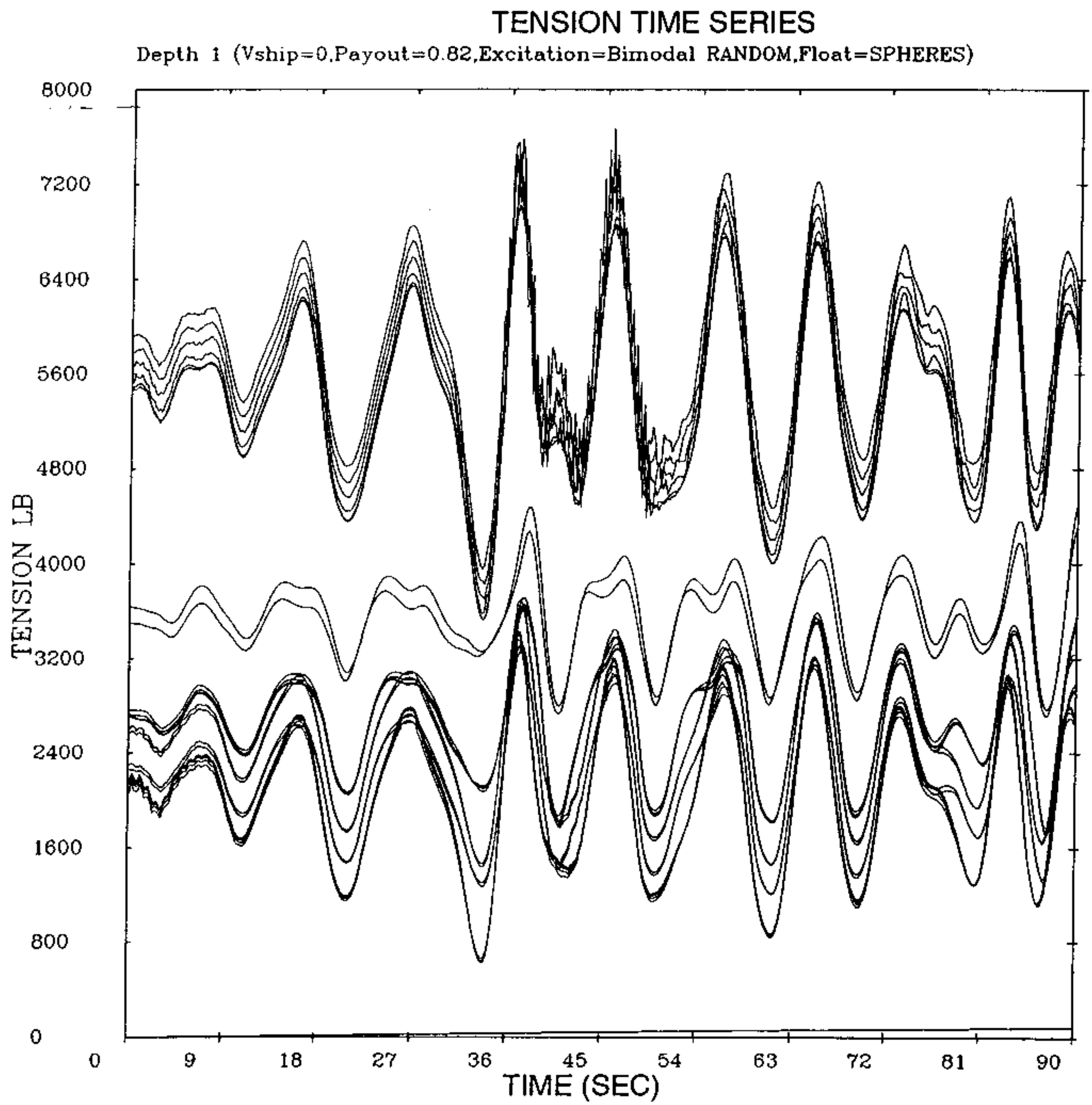
12000
10000
8000
6000
4000
2000
0
-2000
TENSION LB
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)


TENSION TIME SERIES
Depth 4 (Vship=0,Payout=2.46,Excitation=Bimodal RANDOM)
TENSION LB
14000
12000
10000
8000
6000
4000
2000
0
-2000
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)



TENSION TIME SERIES
Depth 1 (Vship=0,Payout=0.82,Excitation=Bimodal RANDOM,Float=SPHERES)
TENSION LB
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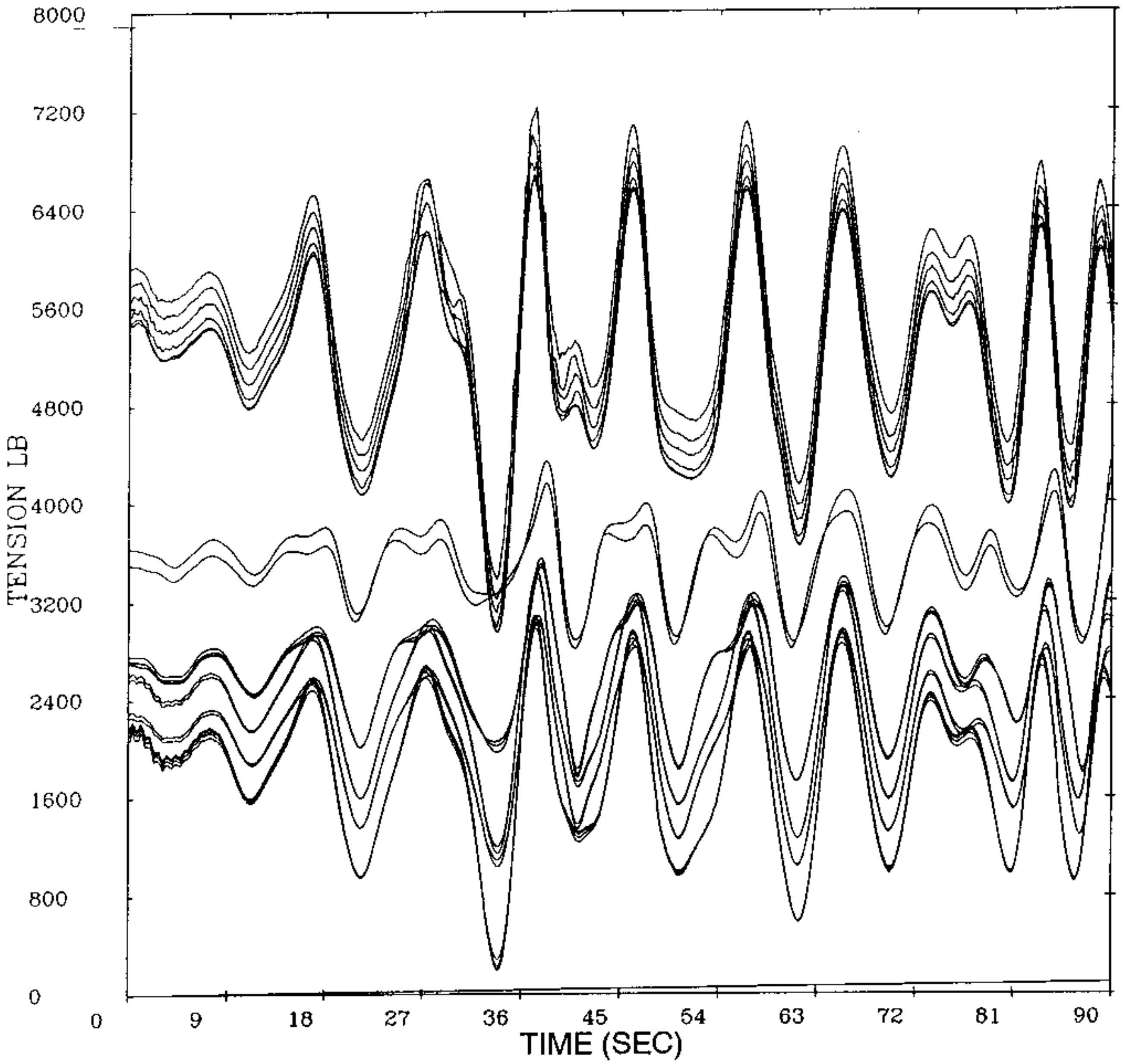
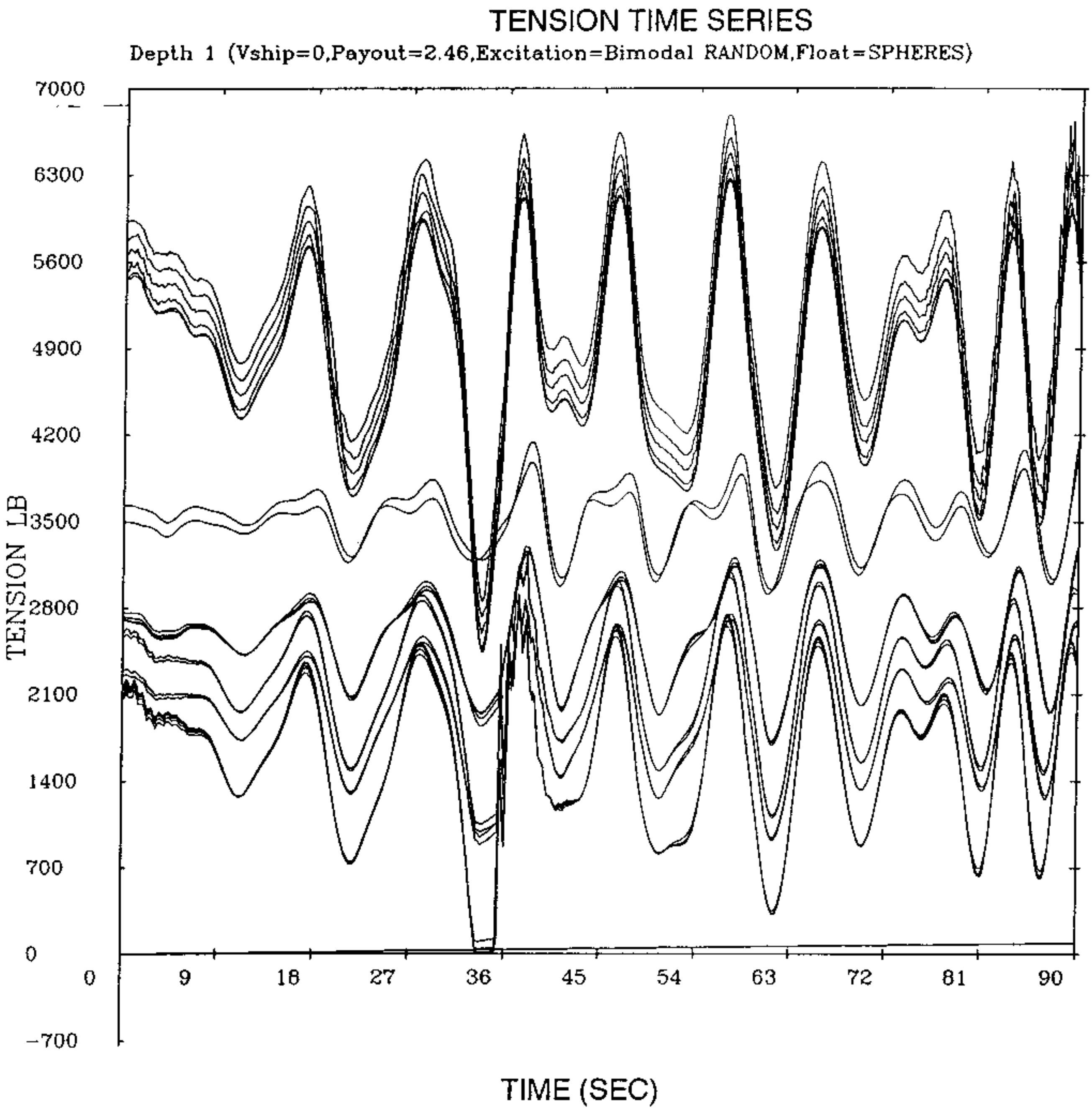
7200
6400
5600
4800
4000
3200
2400
1600
800
0
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)

TENSION TIME SERIES

Depth 1 (Vship=0,Payout=1.64,Excitation=Bimodal RANDOM,Float=SPHERES)




TENSION TIME SERIES
Depth 1 (Vship=0,Payout=2.46,Excitation=Bimodal RANDOM,Float=SPHERES)
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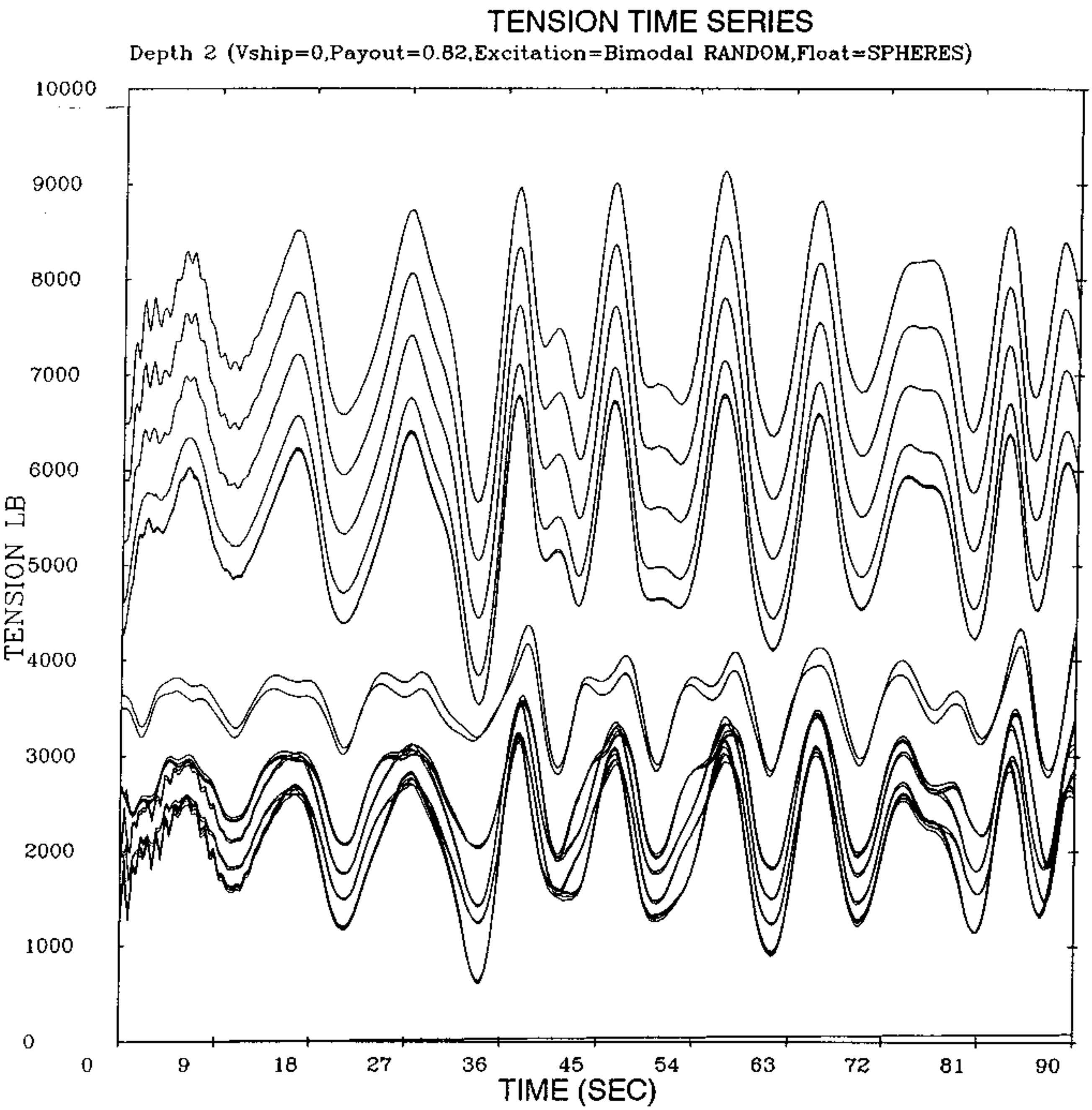
6300
5600
4900
4200
3500
2800
2100
1400
700
0
-700
TENSION LB
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)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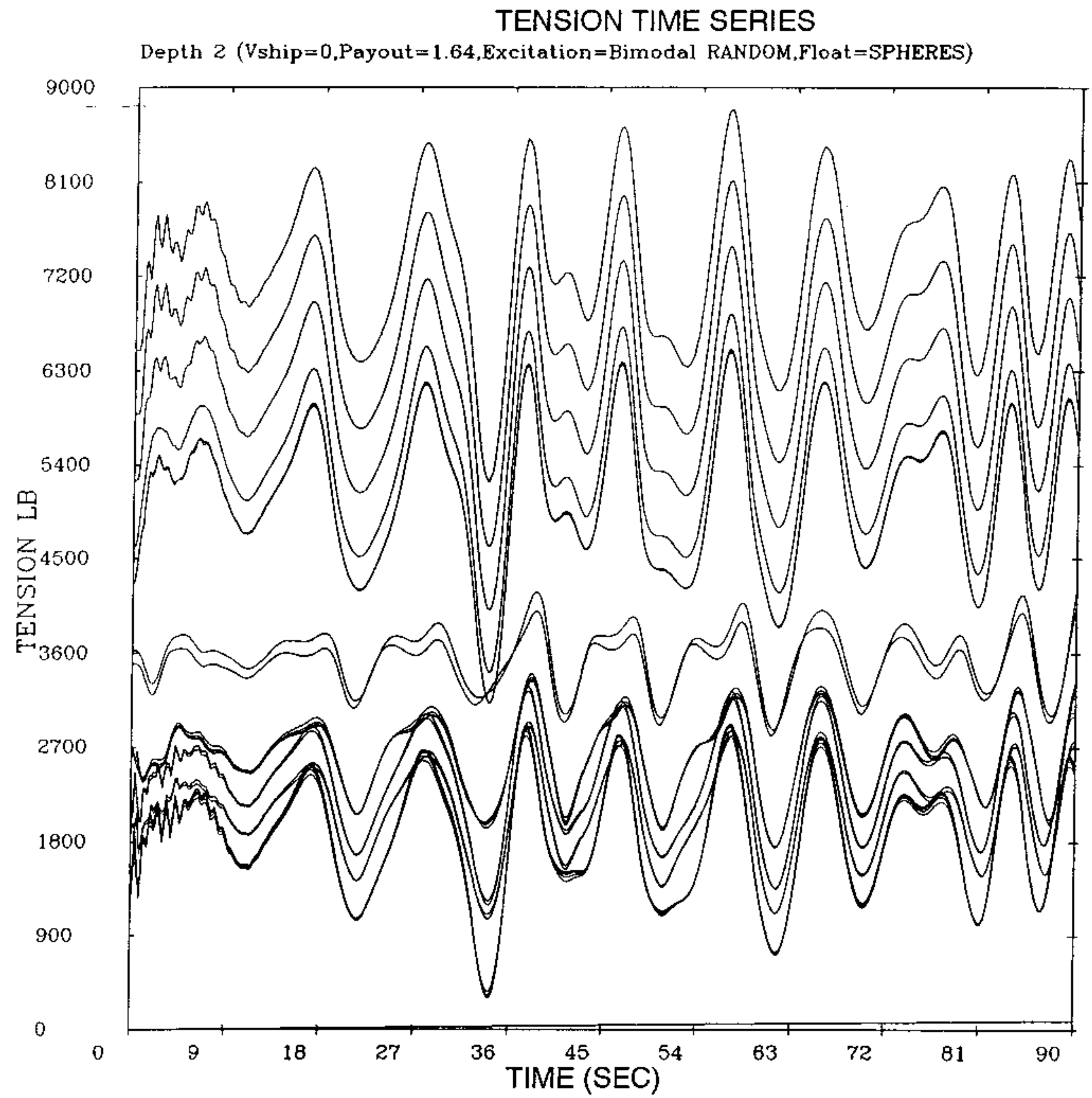
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)


TENSION TIME SERIES
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TENSION LB
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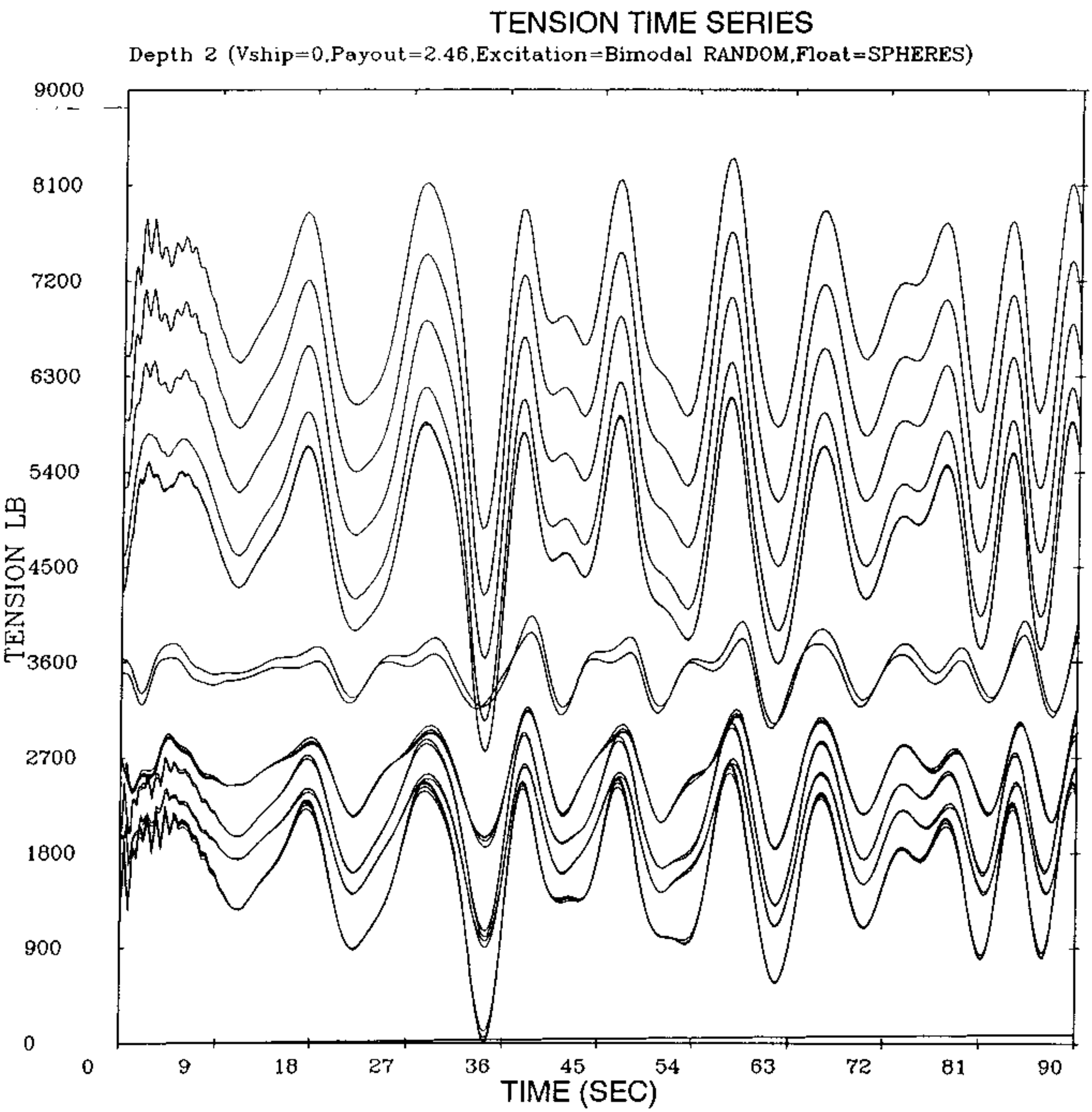
8100
7200
6300
5400
4500
3600
2700
1800
900
0
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)


TENSION TIME SERIES
Depth 2 (Vship=0,Payout=2.46,Excitation=Bimodal RANDOM,Float=SPHERES)
TENSION LB
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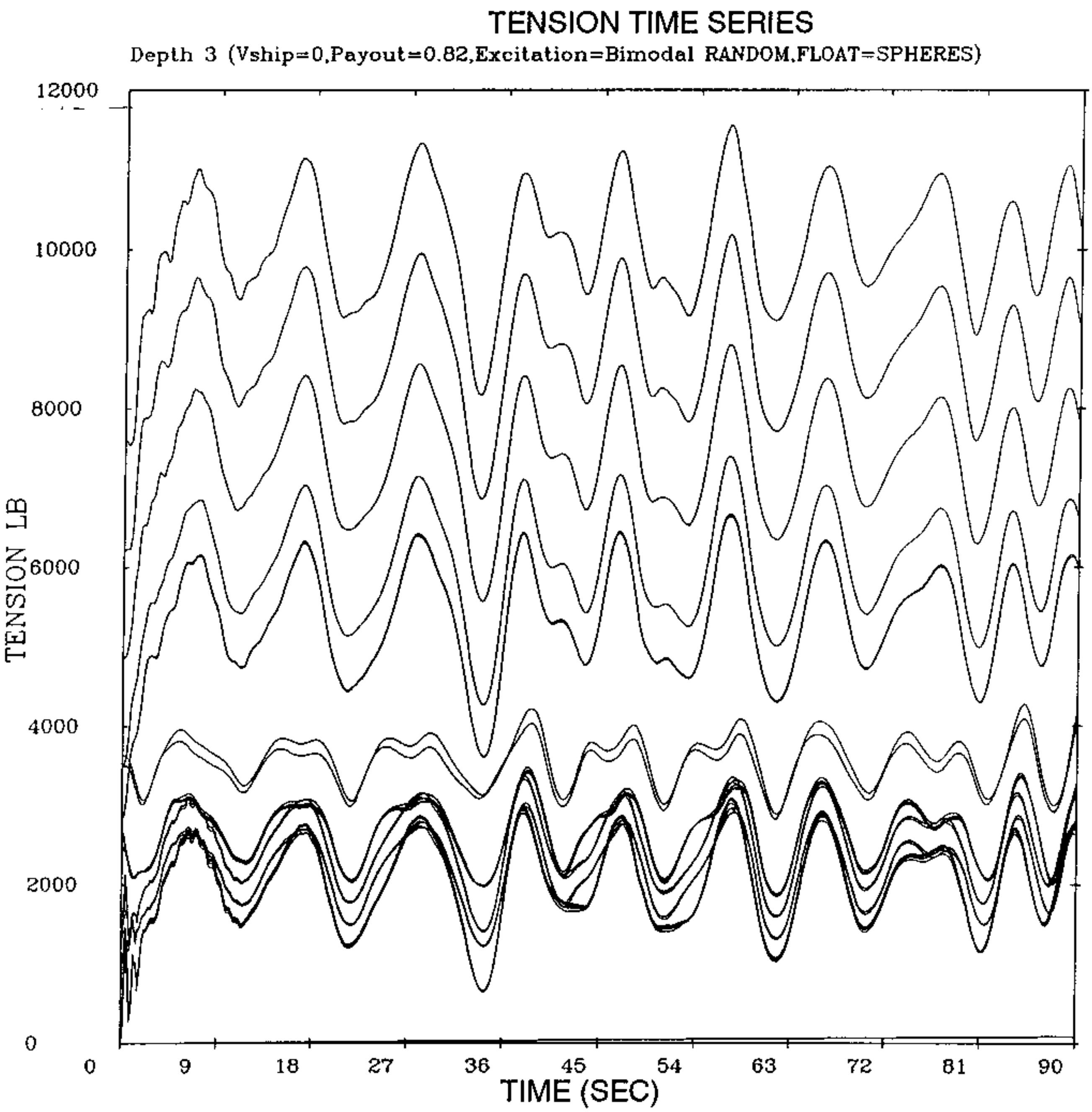
8100
7200
6300
5400
4500
3600
2700
1800
900
0
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)



TENSION TIME SERIES
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10000
8000
6000
4000
2000
0
TENSION LB
0
9
18
27
36
45
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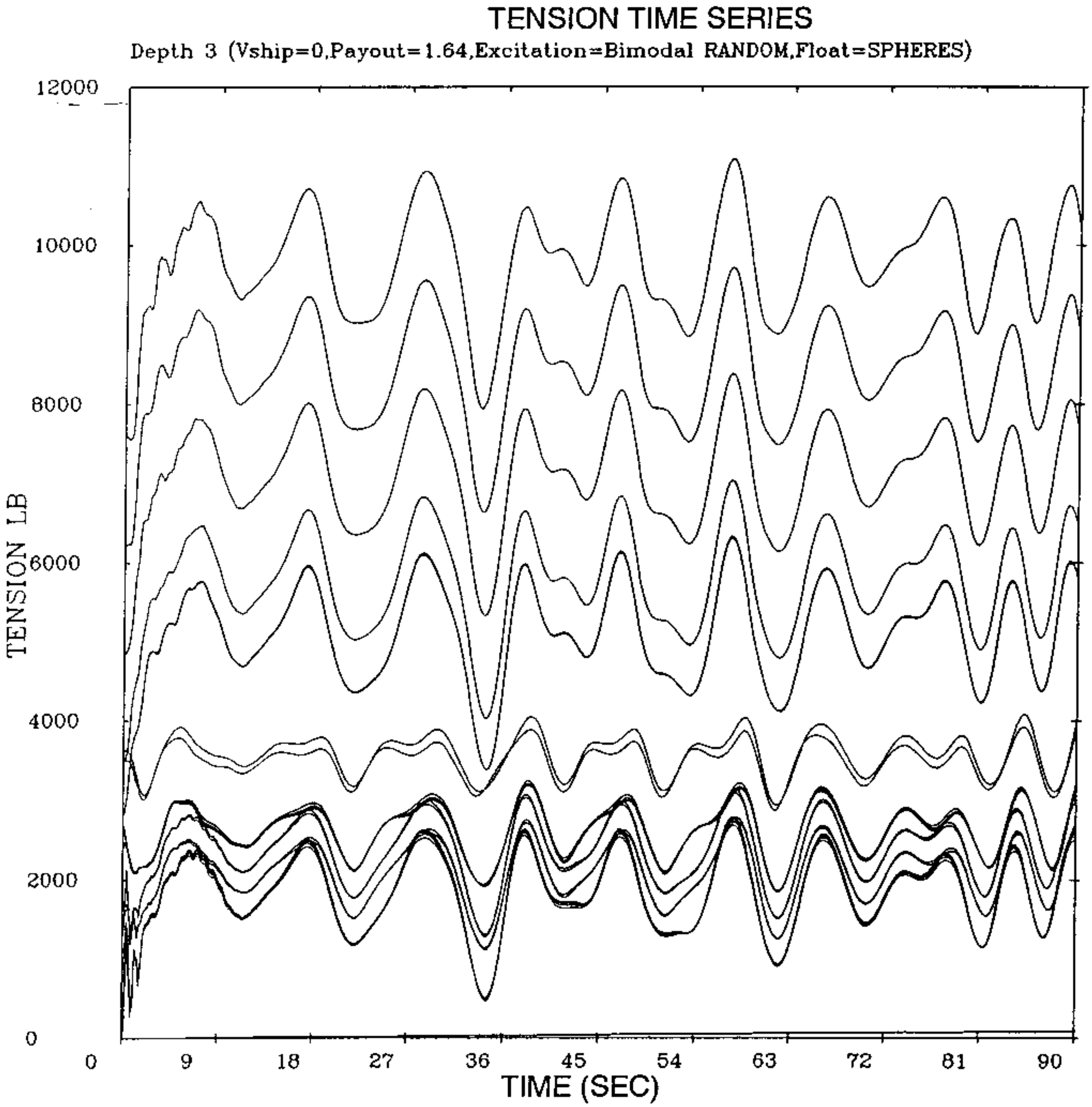
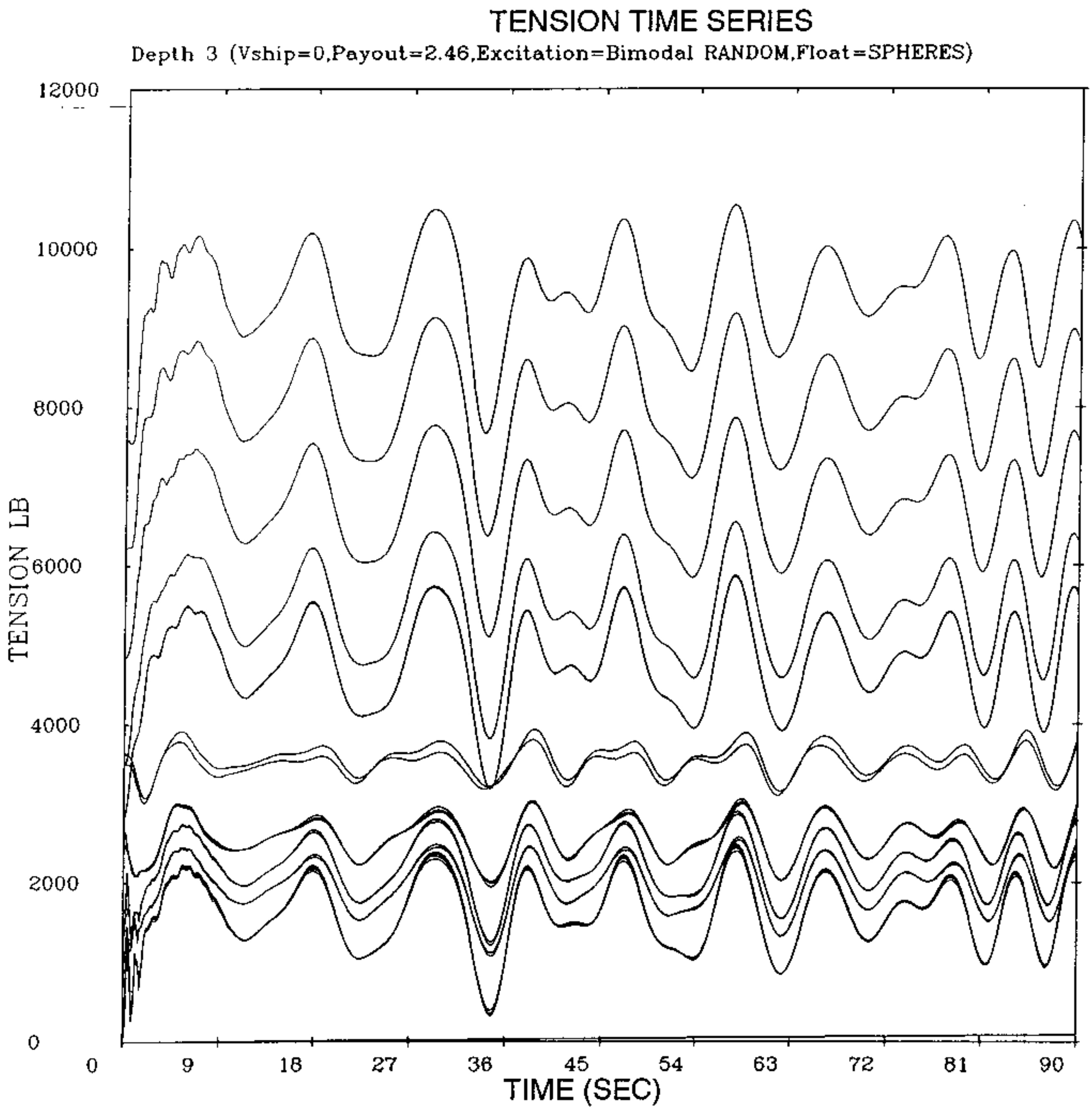
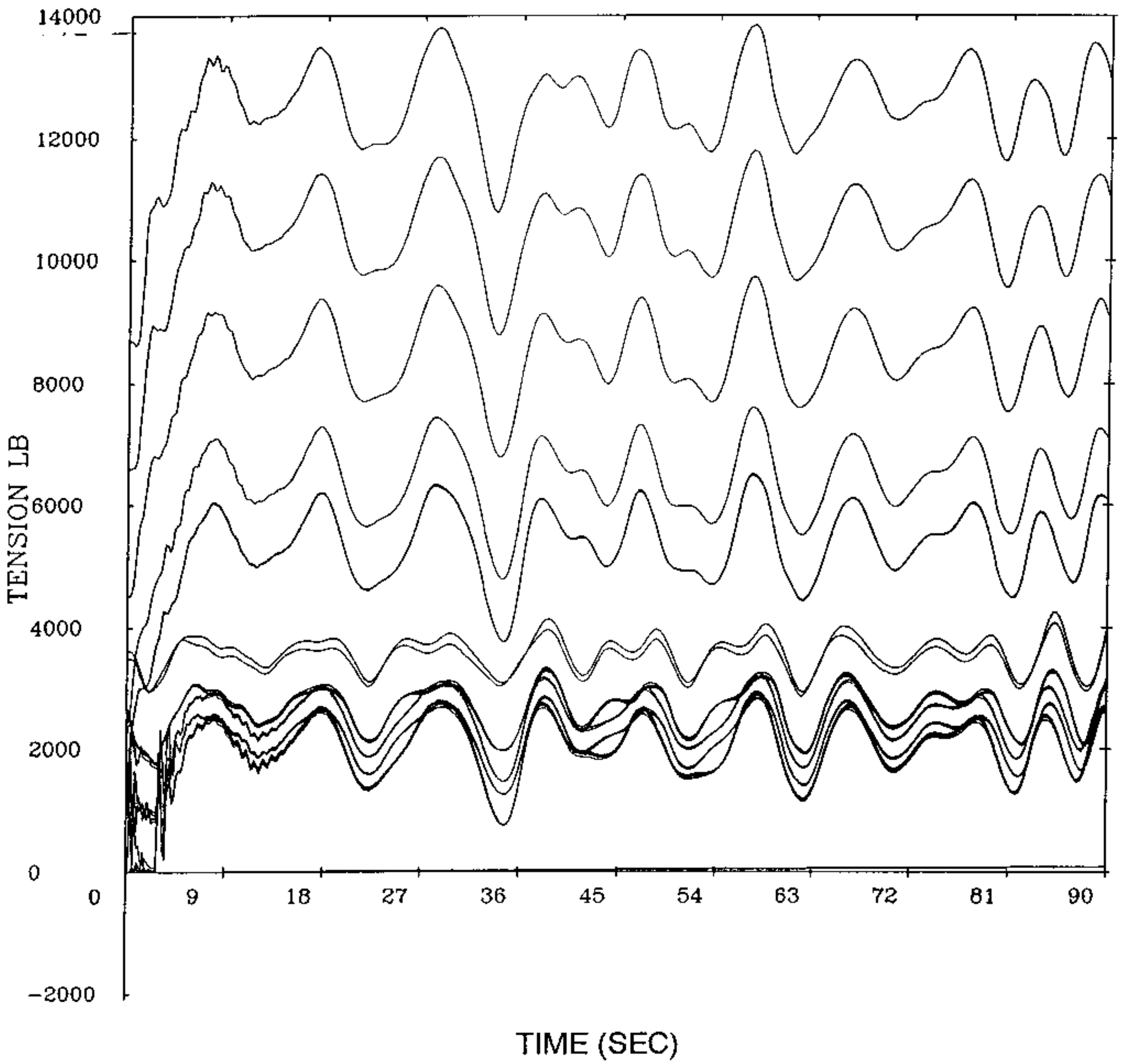
72
81
90
TIME (SEC)

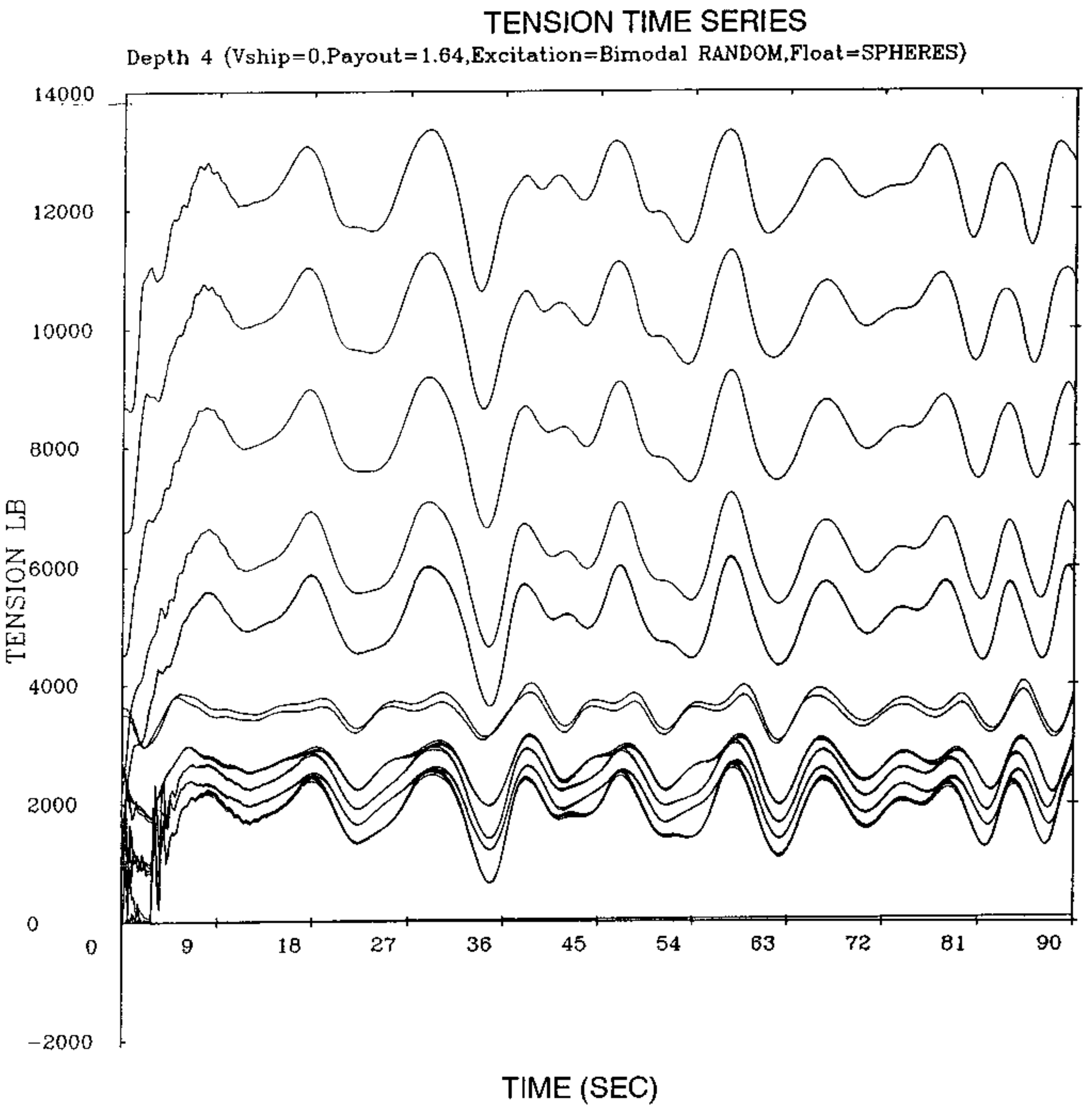

TENSION TIME SERIES
Depth 3 (Vship=0,Payout=1.64,Excitation=Bimodal RANDOM,Float=SPHERES)
TENSION LB
12000
10000
8000
6000
4000
2000
0
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)


TENSION TIME SERIES
Depth 3 (Vship=0,Payout=2.46,Excitation=Bimodal RANDOM,Float=SPHERES)
TENSION LB
12000
10000
8000
6000
4000
2000
0
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)

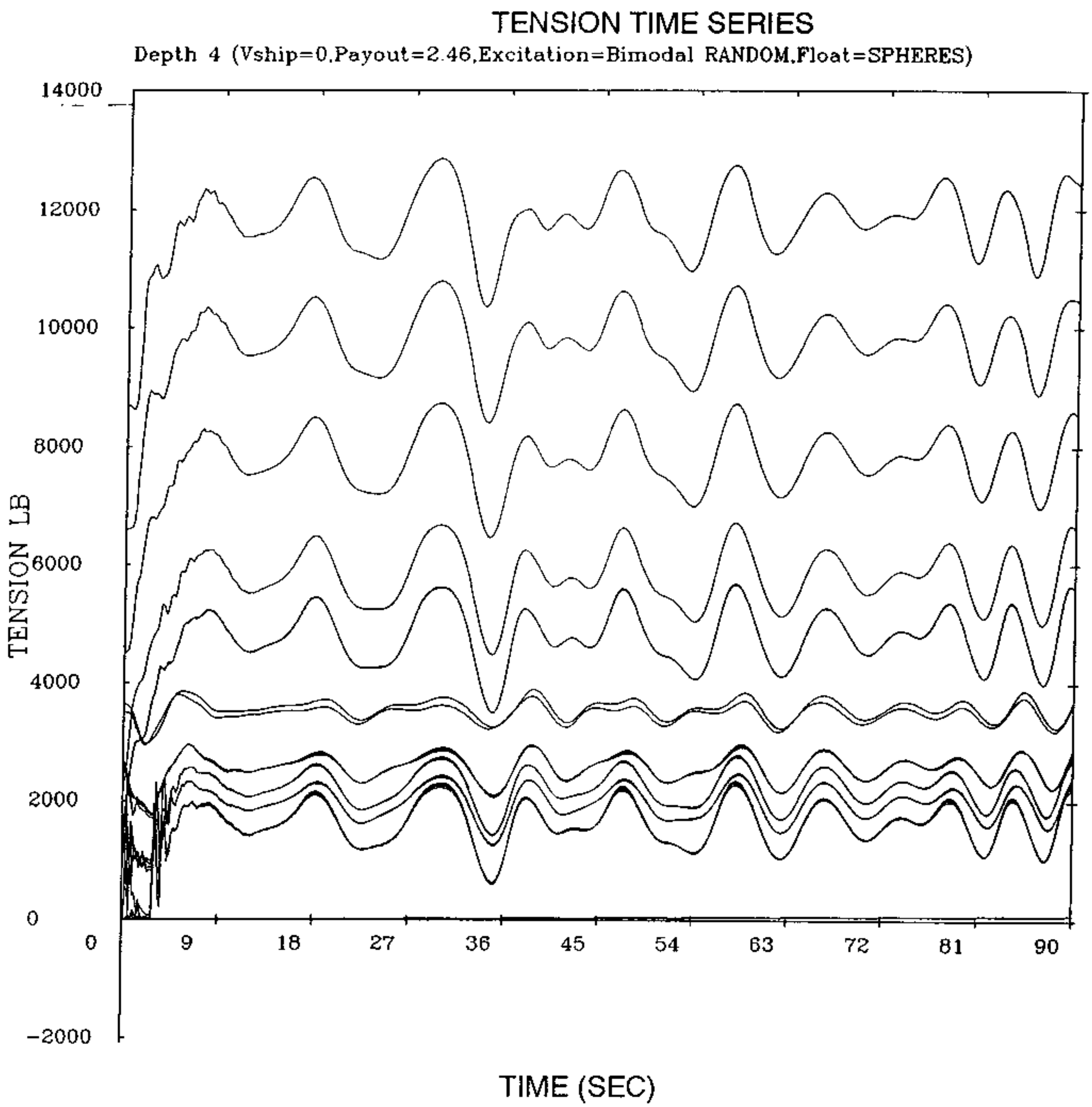
TENSION TIME SERIES

Depth 4 (Vship=0,Payout=0.82,Excitation=Bimodal RANDOM,Float=SPHERES)





TENSION TIME SERIES
Depth 4 (Vship=0,Payout=1.64,Excitation=Bimodal RANDOM,Float=SPHERES)
14000
12000
10000
8000
6000
4000
2000
0
-2000
TENSION LB
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)


TENSION TIME SERIES
Depth 4 (Vship=0,Payout=2.46,Excitation=Bimodal RANDOM,Float=SPHERES)
14000
12000
10000
8000
6000
4000
2000
0
-2000
TENSION LB
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)

PASS II occurred approximately 18 months later. The assignment was to retrieve some of the sensor arrays and replace one of them with a similar system. During the deployment phase, cable pay out and slack control was managed by a slack management system. The unit received speed inputs from the vessel's integrated navigation system and cable pay out rates from the Draw-Off Hold-Back (DOHB) cable traction winch to calculate the actual slack encountered verses desired.

PROGRAM ACRONYM: DWD - DEPLOYMENT DYNAMICS OF SMALL DIAMETER CABLES

During two voyages, the Independence was tasked with the deployment of several lengths of small diameter cables (.10 to .25 inches). On the first voyage, two lengths of cable totaling 9.5 km were deployed. Cables and repeaters were recovered after surveys were made to verify the correct placement and orientation and desired slack of the cable. A second voyage involved the controlled placement of two lengths of small diameter cable 24 km and 20.5 km respectively. Ships velocities were critical to the operation ranging from .5 to 1.5 kts. After deployment, the cable was inspected via ROV to document the in site position of each cable string. The cables and repeaters were recovered at the completion of the voyage.

PROGRAM ACRONYM: TETHER DEVELOPMENT PROJECT DEPLOYMENT

The objective of this project was to evaluate the survivability of various test cables in varied ocean floor environments. Acoustic tracking, integrated navigation and ROV support were used during this operation. The Independence deployed three steel structures, containing 20 individual, 1 km cable samples. Cable were deployed along pre-plotted positions, surveyed in and then recovered in at the completion of the voyage.

PROGRAM ACRONYM: MUTIPLEXED RANGE SENSOR ARRAY DEVELOPMENT

This task involved the controlled placement of a sensor array consisting of approximately 16 nm of cable and repeaters. Deployment depths ranged from 60 ft. to 5700 ft.. Extensive current data and bottom contour data was collected prior to placement of the system. The track of the cable varied as each sensory node was placed on the ocean floor. Approximately two years later, the Independence was tasked to retrieve a portion of the array due to a sensor failure in the system.

PROGRAM ACRONYM: ULF/VLF

This program took place over a three year period. Each phase consisted of deployment of systems and arrays, survey work, bottom sampling, and cable deployments. The Independence laid out approximately 15 miles of fiber optic cable along with attached sensors. All area of operations were surveyed by the Independence for suitability. The system was deployed with the use of a DOHB cable winch and shipboard crane. A ROV inspected the cable and performed specific operations in support of the project. After the final test of each phase were concluded, all hardware and cable were recovered.

PROGRAM: MVX (MODEL VALIDATION EXPERIMENT)

The Independence was tasked to lay out two 20 km packs of Siecor 2.35 mm fiber optic cable with 5 simulated repeaters per string. The cables were inspected following each deployment to collect data on the location, appearance, and amount of installed slack in the cable. The purpose of the project was to study the dynamics of small cable during deployment to the ocean floor. Vessel position, speed, heading, and motions in 6 degrees of freedom, water depth, current velocity profile data, wind speed and direction, cable pay out rate and cable tension were all recorded and monitored. The cable deployment system consisted of an electrically powered winch, a winch control station, and a cable exit device to monitor tension.

PROGRAM: DEEP WATER DEPLOYMENT AT SEA TRIAL

The vessel deployed 10 km of fiber optic cable. prior to deployment side scan sonar was utilized to evaluate the proposed area of operations. All parameters affecting the placement of the cable were recorded. An ROV was utilized to inspect the cable once it was on the ocean floor.

PROGRAM: OUTPOST SUNRISE

An ocean acoustic measurement exercise involving the deployment of vertical arrays and horizontal arrays that measure the low frequency vertical ambient noise field structure of a soft sediment ocean bottom. The system utilized to measure this data was the Versatile Experimental Data Acquisition Buoy System (VEDABS). All systems were deployed from the Independence. These units consisted of vertical arrays containing 25 hydrophones spaced along their length. Each of the VEDABs exceeded 2000 feet in length. The Independence deployed four VEDABs to two separate areas. Other operations performed during this task included towing acoustic projectors, deploying various buoys and acoustic devices, and collecting data from the sensors. The Independence also recovered the vertical arrays at the end of the exercise.

Regards,

Mark H. Wood

APPENDIX 2:
Cable Dynamical Simulations of the Proposed Deployment

Peter Gorham and John Flanagan
University of Hawaii DUMAND Group

Introduction

Dynamic loading of cables in systems where the static loads are well within cable safety factors can still lead to unexpected catastrophic failure. One situation where such failures occur is in dynamic "snaploading" of a cable, which occurs when a cable achieves enough amplitude of motion that the cable goes slack during a cycle, and then subsequently is subject to the full dynamic load of the supported mass (either its own weight or that of an attached package) within a fraction of the normal relaxation cycle. Under these circumstances the cable may experience a load which is much larger and of shorter duration than that caused by the static loads of the supported mass, or even by smooth cyclical dynamic loads generated by wave motion.

Snaploading of the DUMAND cable and string can be expected to be a problem if the drag of the packages is sufficient so that, during the normal heave of the package expected from wave action at the ship, the positive acceleration (toward the surface) exceeds the downward acceleration due to the sum of gravitational and drag forces in some portion of the deployed string so that it becomes slack. Snaploading can be compensated for by increasing the ballast, modifying the drag, decreasing the cable payout rate, or increasing the forward ship speed as cable is paid out. The impulsive effects of snaploads may also be compensated for by introducing different spring constants into portions of the system. However, it is important to assess the degree to which snaploading is a problem before designing a system or procedure to cope with it.

SNAPLD

Because a full physical description of the dynamics of cable motion involves a three dimensional second order partial-differential equation, the problem is usually treated numerically. In this report we have used a finite-element analysis program developed by the Naval Civil Engineering Laboratory, entitled SNAPLD (a part of the SEADYNE package). The program does not deal with the entire 3-dimensional problem, but solves the problem in a plane, which is adequate for our situation. The program has been verified independently by numerous users at NCEL and NRAD San Diego (formerly NOSC).

The general report of the users is that the tensions reported by the program are reasonably accurate until snaploading occurs. The occurrence of snaploads is also reasonably well-predicted. However, the actual tensions experienced by the cable within a snapload situation cannot be guaranteed to be accurate, since the slack cable condition cannot be easily modeled. In any case, the purpose of the program for our case is to predict when dangerous snaploads may be occurring and allow us to avoid the circumstances that create this situation.

A snapload is usually reported by the program when the tension goes to zero, depending on whether or not the zero tension episode is followed by motion with enough amplitude to induce a high tension cycle in the segment for which the program finds a slack condition. Thus in some cases slack conditions do not lead to snaploads if the subsequent acceleration of the segment is low enough. The program is also fairly accurate in predicting oscillations of cable segments, since these can be driven into resonant conditions which lead to snaploads.

Results

The following are the results from two sets of SNAPLD simulations. The two sets of runs are identical, except that the first assumes that the float will be made of syntactic foam, and the second assumes that the float will be made of $\sim$ 20 Benthos spheres. The runs with the spheres are marked with "Float=SPHERES" in the title. The distinction between these two types of float was made because the two float configurations provide distinctly different drag geometries and dynamic behavior. In the first case, the float is a single cylindrical section of order 1 m in diameter and about 2 m long. In the second case, the floatation is provided by a 100 m string of $\sim$ 20 individual glass floatation spheres in polyethylene hardhats. Thus the results from the two different runs give some idea of the variation in dynamical behavior that can be expected from substantial changes in the geometry of the string.

Table 1 following the text shows the configuration of the finite element segments as seen by SNAPLD, in upside-down order from the actual deployment order (this is the order in which SNAPLD must integrate the tension). Figure 1 shows the input power spectrum of the surface displacement which is used to seed the generator for the random time series, shown in Fig. 2. In Fig. 2(a) the average peak to peak displacement is seen to be about 5-7 feet. Fig.s 2(b) and (c) show the corresponding velocity and acceleration.

Figures 3(a)-10(c) show the resulting tension time series. For each float configuration, there are 12 90-second runs, made at various depths and payout speeds. (The relatively short duration of the runs is due to computing limitations; SNAPLD was written for older architecture with very little memory and has not yet been upgraded to a modern level of efficiency). There are 4 depths used in the simulations:

Junction Box height from seafloor	Anchor height from seafloor
Depth 1: 4484 m	3596 m
Depth 2: 3631 m	2743 m
Depth 3: 2412 m	1524 m
Depth 4: 1245 m	305 m

The three payout speeds, noted in the plot titles in ft/s, are: (a) 0.82 ft/s (15 m/min), (b) 1.64 ft/s (30 m/min), and (c) 2.46 ft/s (45 m/min). The right side panel in Figure 3(a) shows the actual tension heirarchy that obtains for each of the following figures in terms of the corresponding link. This requires some interpretation: for example, the "junction box" link tension is measured below the junction box termination itself; the actual tension due to the weight of the junction box is felt in the "JB spring section" just above it. Thus in general the tension corresponding to the weight of a given link must be interpreted according to the links adjacent to it, as given in Table 1.

Other than variations in payout speed, depth, and float configuration, all of the runs are identical. In particular, the speed of the ship is always held constant at 0, and the excitation which is applied at the surface end is always the same displacement time-series, generated from a bimodal power spectrum with peaks at 12-sec period and 6-sec period. These correspond to expected contributions from ocean swells and ship rocking for the Charlie Brown in sea-state III.

It should be noted that the initial few seconds of the resulting time series are affected to some degree by transient response of the system and do not reflect actual conditions in the cable. This is evident in Fig. 4 for example, where cable vibrations commence immediately, but then die out within 10-15 sec. However, in Fig. 4(c), where a zero tension episode is encountered, the same vibration is again excited and in this case is probably physically present.

Discussion

As discussed in a previous section, the episodes in which a link of cable goes to zero tension are of the most concern. An example of this is seen in nearly all of the Depth 1 and 2, Payout=2.46 runs for both float configurations. A couple of the kevlar riser sections go through zero tension, and come near to inducing a snapload. (Actual "snaps" were not reported by the program in these cases, however, since the tension recurs gracefully enough in all episodes.)

The reason for this is that the string section, with its accompanying buoyancy from the OMs, is much lighter than the junction box, and it is unable to track the junction box when the two are falling with downward surface displacement. Thus the OM riser section develops slack during these falls. This problem is most acute near the surface, where there is very little intervening cable to damp the amplitude of the wave-induced acceleration. When the system is deep, it is evident that the problem is relieved considerably by cable damping.

It is also apparent that lower payout speeds improve things. The reason for this becomes evident when one considers the extreme case of a large payout velocity which equals the terminal velocity of the OM riser section: in that case, the tensioning this section would become identically zero. However, since the terminal velocity of the junction box is higher than that of the OM riser sections, it would remain under tension, still coupled to the surface displacement, and extreme snaploading would result. Thus it is desirable that the payout velocity remain low enough at any portion of the deployment so that the terminal velocity of any section of the system is still significantly higher than sum of the maximum downward displacement velocity and the payout velocity. An alternate approach to achieve these conditions without changing payout velocity it to use forward ship motion to produce the same relative motion that a decrease in cable payout might produce. Thus careful orchestration of both payout speed and ship speed can relieve snaploading problems considerably.

The worst case motion during this time series occurs at about the 36 sec mark, when the seas combine to produce peak-to-peak pitch motions of about 7 and 7.5 feet back-to-back. A study of wave heights at Keahole Point (Noda and Associates 1983) indicates that the probability of getting wave heights less than 4 feet for a given day exceeds 50% for the entire year. Although conditions at the DUMAND site can differ from Keahole Point due to the influence of trade wind swell from the Alenuihaha channel, this effect does not often produce conditions that exceed sea state III except during strong trade wind weather.

Conclusions

The results show that the deployment scenario outlined in this document does not introduce excessive dynamic loading of the components of the system, provided the operations are done in sea state conditions no worse than sea state III, and preferably better, from a vessel with pitch characteristics similar to the Charles Brown. This constraint is not a severe one for the DUMAND site; local experience at the site indicates that such conditions are probably satisfied well over 50% of the time during most of the year.

In addition to observing the sea state limitations, the deployment planners must pay close attention to payout rates of the cable so as not to induce a snaploading situation in the kevlar sections of the string. It appears that for the syntactic float configuration, a payout rate of 15 m/min (0.82 ft/sec) should be maintained until the string is about halfway down, at which point a payout rate of 30 m/min (1.64 ft/sec) could be adopted. For the spheres float configuration, a maximum payout rate of 30 m/min could be observed until about halfway down, and then 45 m/min thereafter. This skirts the margin of safety, and prudence would indicate a lower payout rate similar to the syntactic float: 15 m/min for the first half, and 30 m/min thereafter seems to give a few hundred pounds leeway. If these guidelines are followed, it does not appear necessary to us a surface motion-compensation system during the deployment, although any such system would improve the overall safety factor.

References

"Frequency and Height of Waves at Keahole Point, Hawaii," 1983, E. K. Noda and Associates, Engineering study prepared for Hawaiian Dredging and Construction Co. as part of the OTEC CWP at-sea test program, phase 3.

Table and Figure Captions

Table 1

The configuration of the string as presented in finite element form to SNAPLD, upside-down from the deployment orientation (which itself has the string in an upside-down orientation).

Figure 1

The input power spectrum of waves used as source distribution for generating the random time series.

Figure 2

(a) The vertical displacement time series used as input to SNAPLD. (b) The corresponding vertical velocity time series. (c) The corresponding acceleration.

Figure 3

(a) SNAPLD results for the depth and payout speed given at the top of the plot, for a float which is a single large syntactic foam cylinder. The side panel indicates the various elements that are simulated, with the order from top to bottom the same as the corresponding data trace in the plots. (b), (c) Similar results for different payout speeds.

Figures 4,5,6

Similar to Fig. 3., but with varying depths.

Figures 7,8,9,10

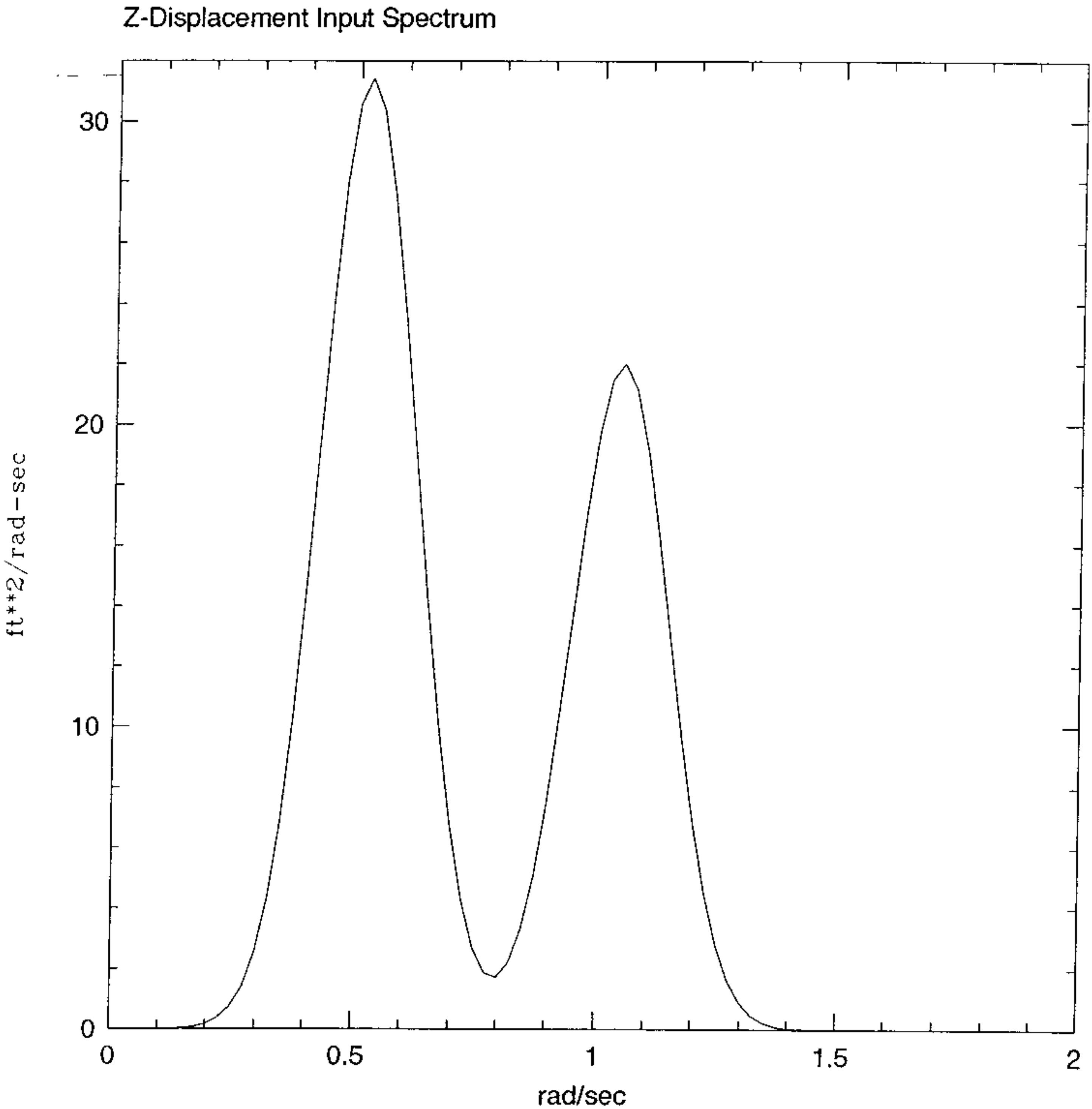
Similar to Fig.s 3-6, but with a string of Benthos glass floats instead of syntactic foam.

TABLE 1

Ball-float configuration

(Upside-down)

Node	Link	Cable	Seg. Length	x, vx, z, vz	Comments
0				0,0,11836,0,	/*Anchor*/
	1	1	738		
1				0,0,12574,0,	/**/
	2	1	738		
2				0,0,13312,0,	/*Float*/
	3	2	164		
3				0,0,13476,0,	/**/
	4	2	164		
4				0,0,13640,0,	/*Cable_End*/
	5	3	94		
5				0,0,13734,0,	/**/
	6	3	94		
6				0,0,13828,0,	/*OMs_13-24*/
	7	4	94		
7				0,0,13922,0,	/**/
	8	4	94		
8				0,0,14016,0,	/*SC*/
	9	5	94		
9				0,0,14110,0,	/**/
	10	5	94		
10				0,0,14204,0,	/*OMs_1-12*/
	11	6	94		
11				0,0,14298,0,	/**/
	12	6	94		
12				0,0,14392,0,	/*Cable_End*/
	13	7	82		
13				0,0,14474,0,	/**/
	14	7	82		
14				0,0,14556,0,	/*Cable_End*/
	15	8	82		
15				0,0,14638,0,	/**/
	16	8	82		
16				0,0,14720,0,	/*JB*/
	17	9	164		
17				0,0,14884,0,	/**/
	18	9	164		
18				0,0,15048,0,	/*Cable_End*/
	19	10	200		
19				0,0,15248,0,	/**/
	20	10	200		
20				0,0,15448,0,	/**/
	21	10	200		
21				0,0,15648,0,	/**/
	22	10	200		
-------Waterline					
22				0,0,15848,0,	/*Payout_Point*/
	23	10	200		
23				0,0,16048,0,	/*Unused_Cable*/
	24	10	200		
24				0,0,16248,0,	/*Unused_Cable*/
	25	10	200		
25				0,0,16448,0,	/*Unused_Cable*/
	26	10	200		
26				0,0,16648,0,	;/*Unused_Cable*/



Z-Displacement Input Spectrum
30
20
10
0
ft**2/rad-sec
0
0.5
1
1.5
2
rad/sec

FIGURE 1

RANDOM VERTICAL DISPLACEMENT AT SURFACE

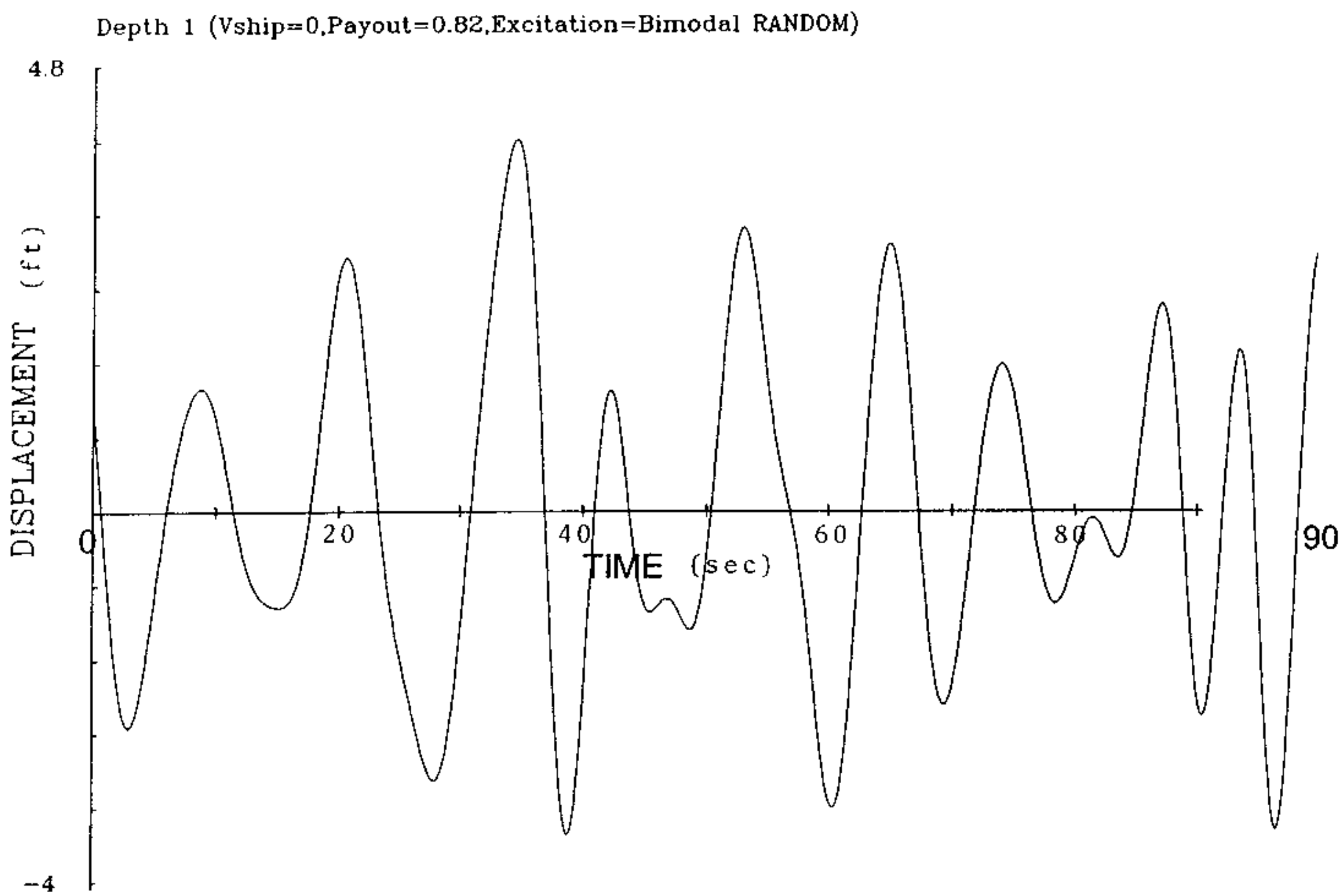


FIGURE 2 2A

RANDOM VERTICAL VELOCITY AT SURFACE

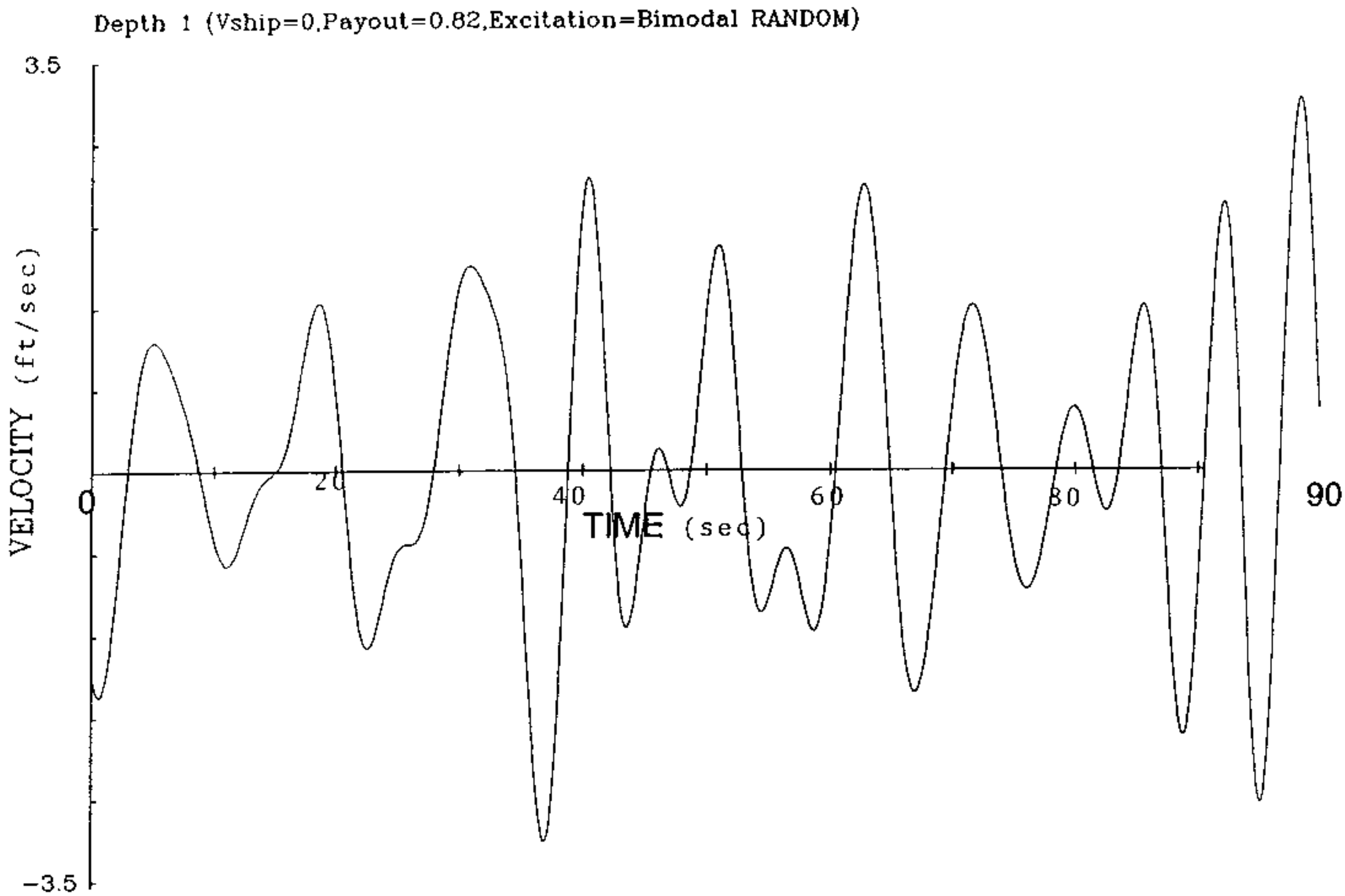


FIGURE 2 B

RANDOM VERTICAL ACCELERATION AT SURFACE

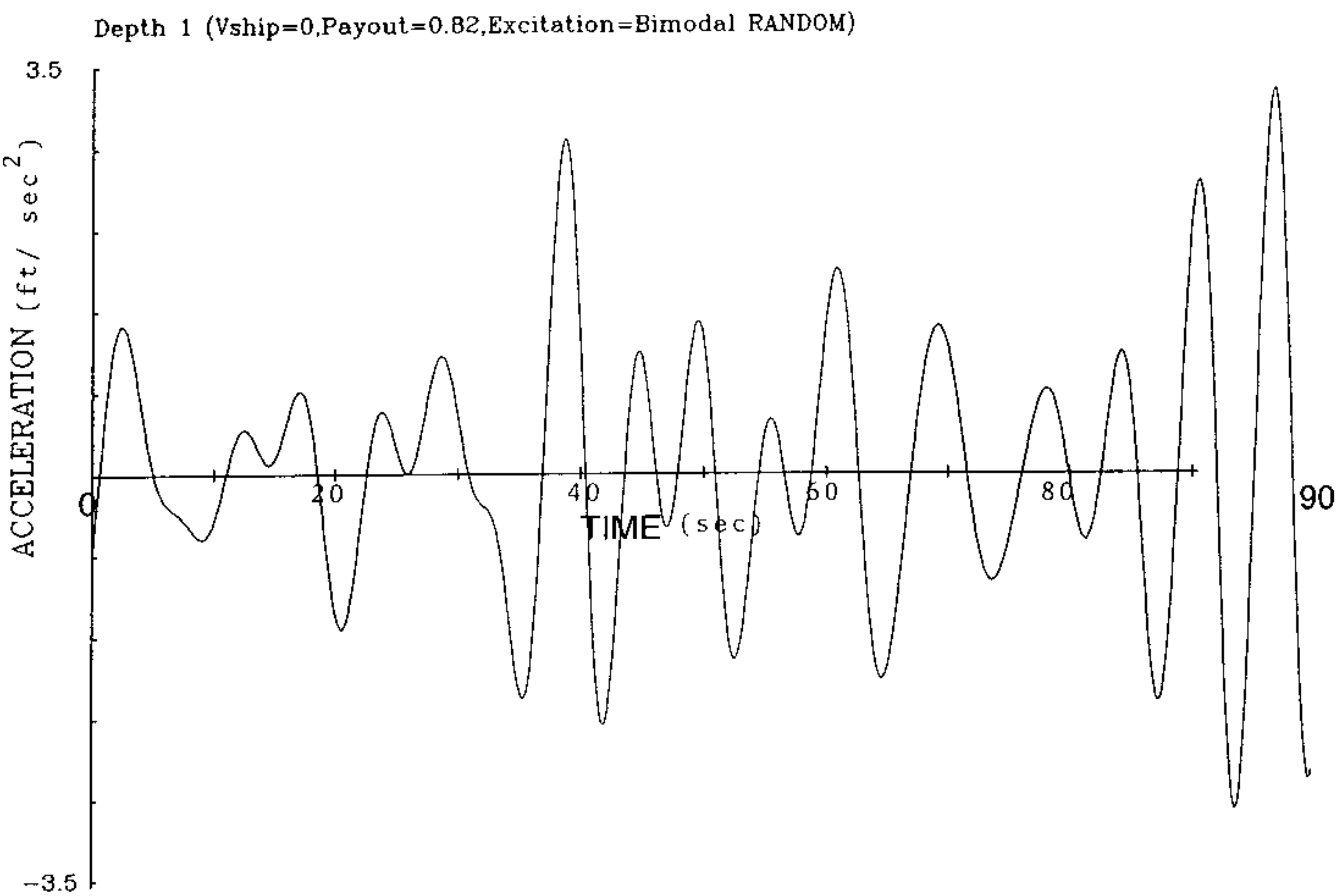


FIGURE 2 C

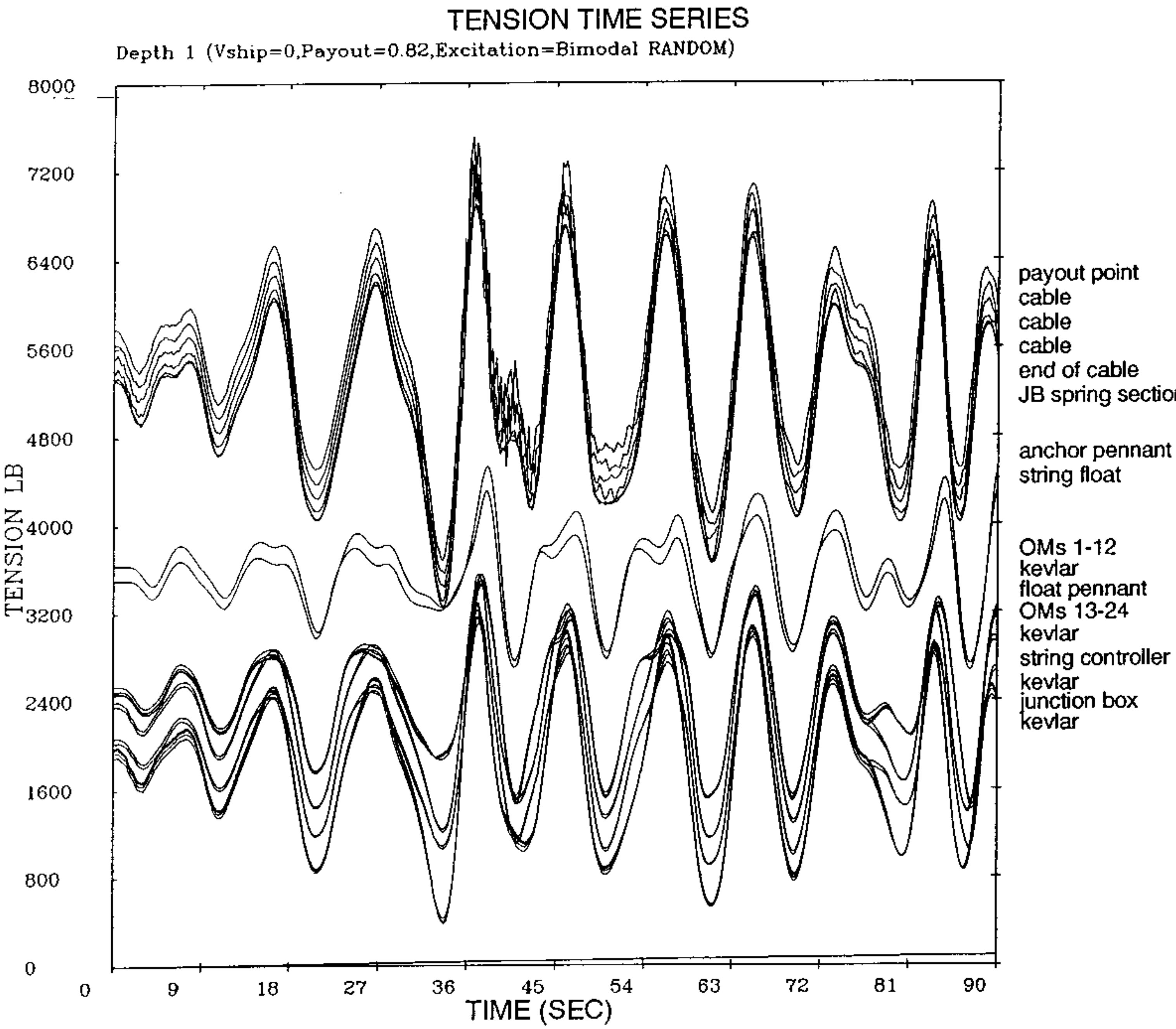
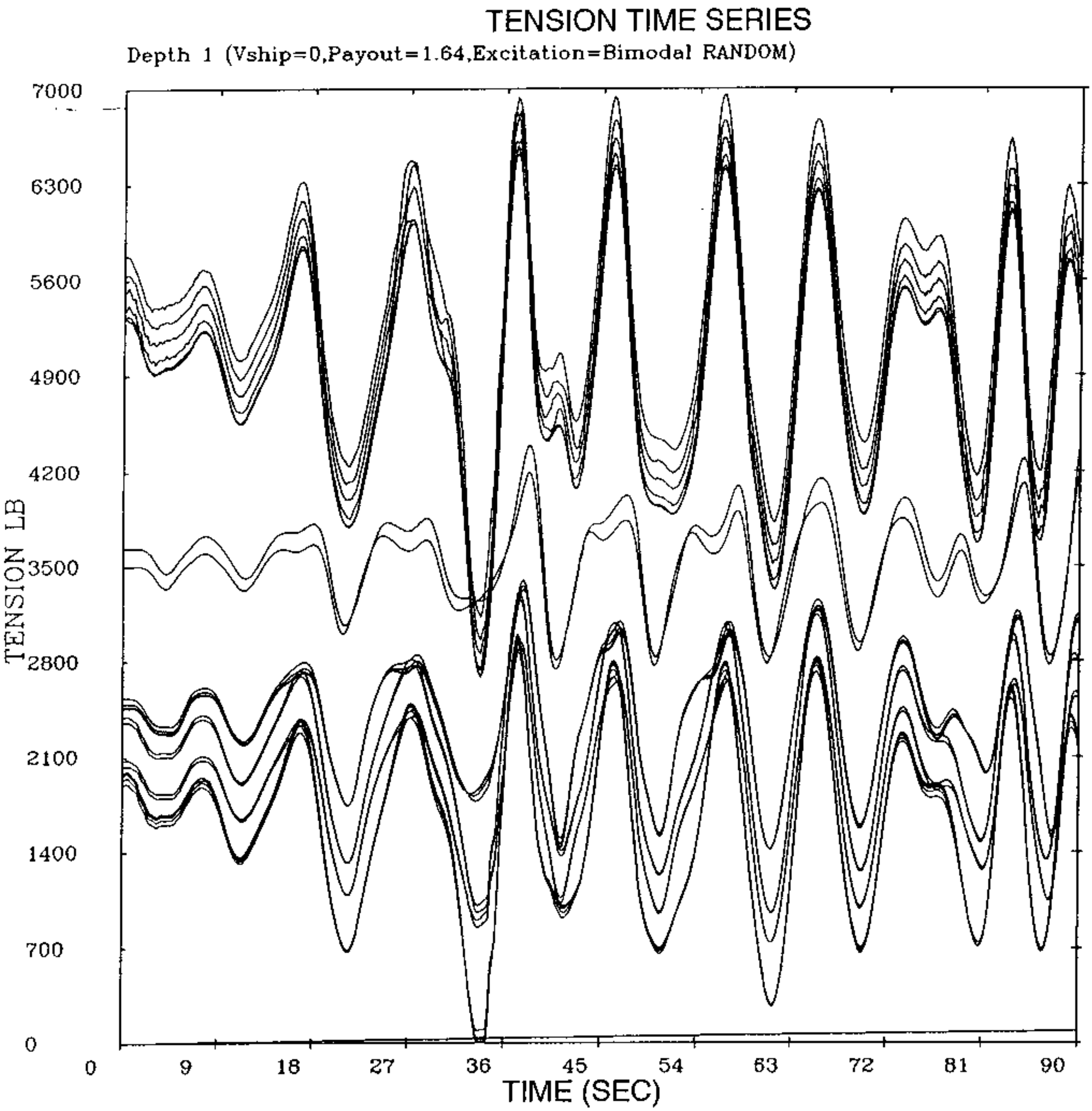
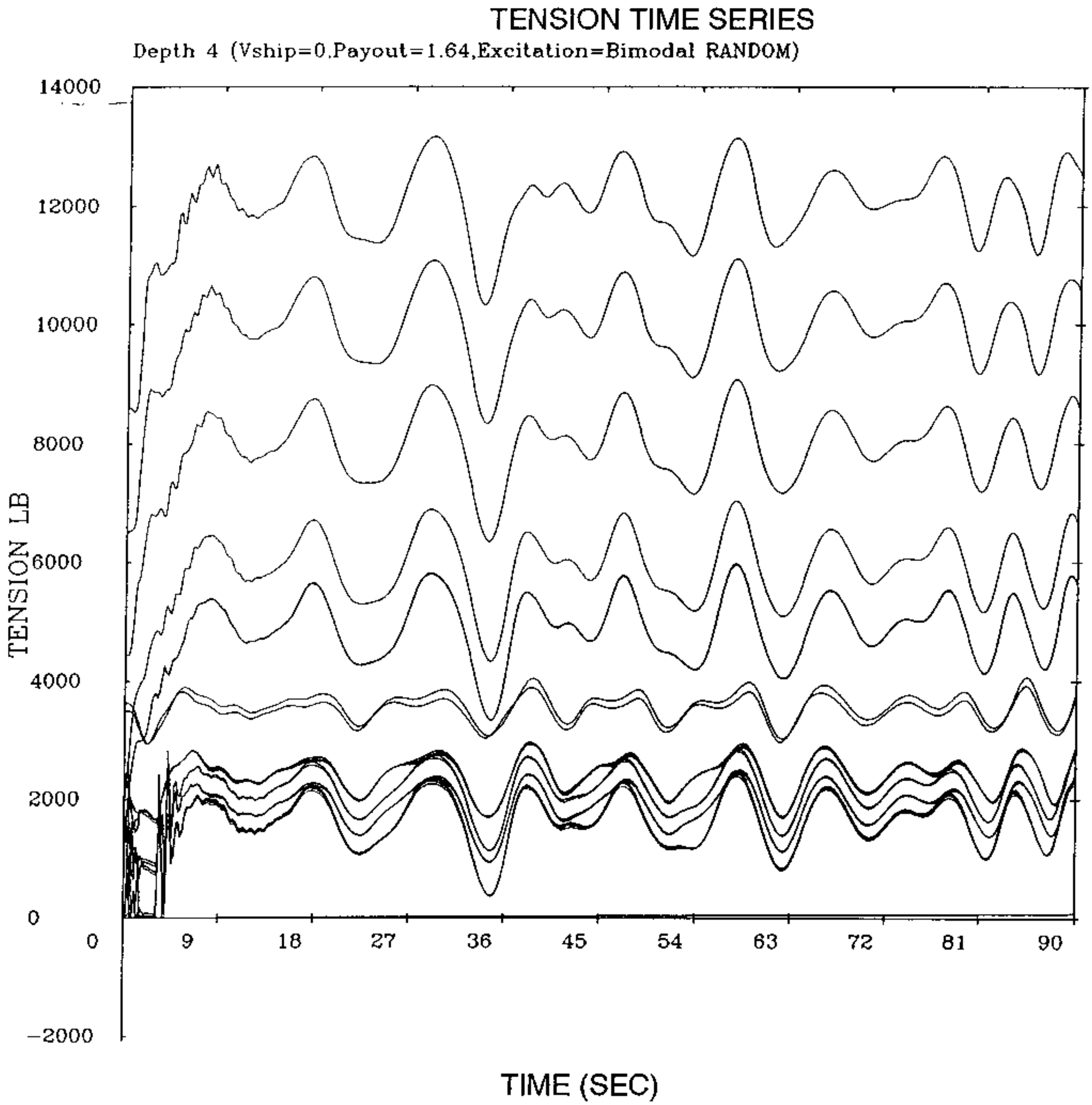
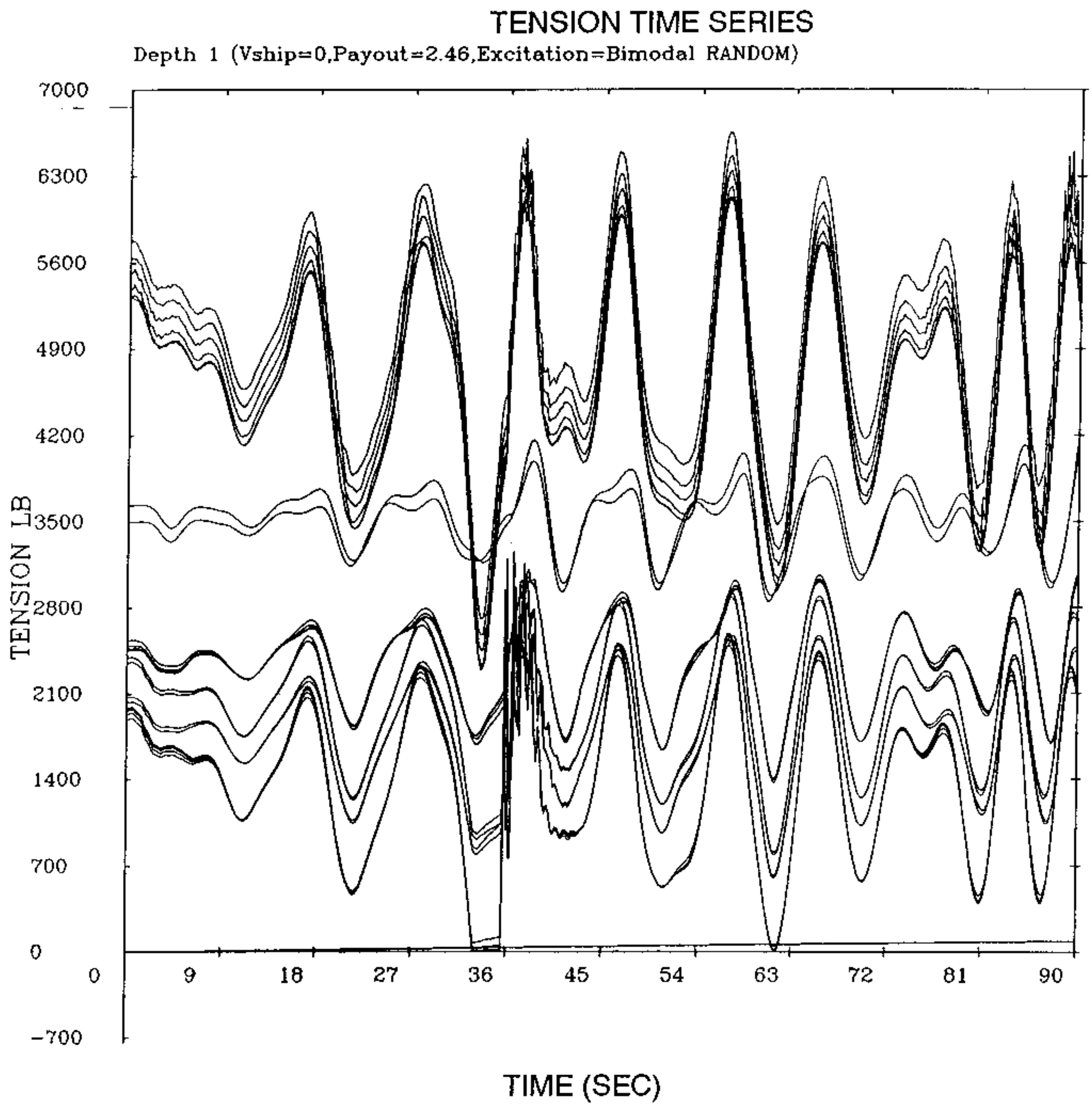

TENSION TIME SERIES
Depth 1 (Vship=0,Payout=0.82,Excitation=Bimodal RANDOM)
8000
7200
6400
5600
4800
4000
3200
2400
1600
800
0
TENSION LB
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)
payout point
cable
cable
cable
end of cable
JB spring sectior
anchor pennant
string float
OMs 1-12
kevlar
float pennant
OMs 13-24
kevlar
string controller
kevlar
junction box
kevlar

FIGURE # 3 A


TENSION TIME SERIES
Depth 1 (Vship=0,Payout=1.64,Excitation=Bimodal RANDOM)
TENSION LB
7000
6300
5600
4900
4200
3500
2800
2100
1400
700
0
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)


TENSION TIME SERIES
Depth 4 (Vship=0,Payout=1.64,Excitation=Bimodal RANDOM)
14000
12000
10000
8000
6000
4000
2000
0
-2000
TENSION LB
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)


TENSION TIME SERIES
Depth 1 (Vship=0,Payout=2.46,Excitation=Bimodal RANDOM)
TENSION LB
7000
6300
5600
4900
4200
3500
2800
2100
1400
700
0
-700
0
9
18
27
36
45
54
63
72
81
90
TIME (SEC)