DOE/NOAA/OTEC-20

MEASUREMENT OF POLYETHYLENE PIPE PARAMETERS DURING AN OCEAN DEPLOYMENT

Final Report

By
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P. L. Ritchie

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November 15, 1978

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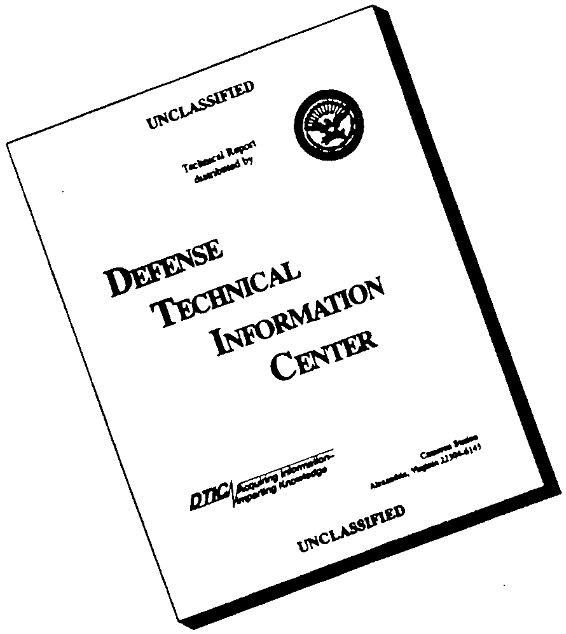

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FINAL REPORT

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DURING AN OCEAN DEPLOYMENT

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NOVEMBER 15, 1978

R.F. HOPPMANN
P.L. RITCHIE

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SUMMARY

This program was conducted to acquire data on the behavior of the polyethylene upwelling pipe for the GRI/DOE Marine Biomass Biological Test Farm during several phases of pipe assembly and ocean towing and deployment. The pipe is nominally 28 in O.D., 1,400 feet long with wall thicknesses of 0.9 and 1.75 inches. The entire effort was conducted over a period of six weeks and was implemented on a strictly non-interference basis with the main Biomass Program.

Three types of data were acquired during shore and ocean based operations conducted in the southern California area during the period from 15 September - 27 September 1978. Axial strain data were obtained from two rows of 15 transducers each, separated circumferentially by 90° and distributed along the entire length of the pipe. Photographic data were also acquired from helicopter, boat and shore stationed cameras. Both 16 mm motion pictures and 35 mm slides were taken. Strain-transducer and photographic data were acquired during beach assembly operations and during a tow and up-ending operation which subsequently had to be aborted before any significant pipe lowering was accomplished.

The third type of data acquired were lowering line tension measurements made during the second successful deployment operation. No strain data were acquired since the sensor harness system was irreparably damaged during the earlier deployment attempt.

The sensor system performed well until problems with the deployment were encountered. Although data reduction/analyses were outside the scope of this program, a limited data scan was conducted. The maximum strain level recorded was only 0.5% and that was encountered in going over the sea wall during assembly

operations. Maximum strains measured at sea during tow were on the order of 0.1%. The most severe bend introduced in the pipe was also seen in going over the sea wall. Minimum bend radii during the towing operations are estimated to be no less than 350-400 feet which is approximately 175 to 200 pipe diameters compared to the sharpest allowable bend of 50 pipe diameters. The lowering line average tension during the final lowering operation was approximately 18,000 lbs compared to the allowable range of 5,000 - 30,000 lbs defined in the deployment plan. Large, transient tension variations (min. 10,000 to max. of 30,000 lbs) were observed during passage of large swells or in a few cases, when the lowering cable shifted on the payout drum. No difficulties were encountered due to these variations.

Several recommendations are made for consideration in future data acquisition efforts of this type.

1.0 INTRODUCTION AND BACKGROUND

The Energy from Marine Biomass Program originated by GRI and presently jointly sponsored by GRI and DOE deployed the first Biological Test Farm off Laguna Beach, California in September 1978. The objective of the testing is to demonstrate and quantitatively evaluate the controlled growth of the California Giant Brown Kelp (Macrocystis pyrifera) in an open ocean environment using deep nutrient-rich water to fertilize the plants. The upwelled water is pumped to the surface from a depth of 1,400 feet through a large 28 in O.D. polyethylene (PE) pipe with nominal wall thicknesses of 1.75 inches (upper 600 feet) and 0.92 inches (lower 800 feet). The pipe (DuPont of Canada, Sclairpipe) was planned for assembly on the beach at Dana Point, California with a nine-mile open ocean horizontal tow to the site of the installation (33° 30' N, 117° 51' W). The pipe was then to be upended to the vertical position and attached to the previously installed buoy system containing pumps, etc.

Early in 1978, NOAA and GE began discussing the possibility of obtaining "piggy-back" data on the behavior of large PE pipes during ocean operations from the Marine Biomass upwelling pipe installation. The data are of interest to NOAA (and DOE) for application to design of OTEC cold water pipe (CWP) systems presently in progress and planned for the future. Since some of the CWP concepts involve the use of PE pipe, although significantly larger than the biomass upwelling pipe, the biomass pipe installation provided a near term and relatively inexpensive opportunity to acquire the "piggy-back" data on a non-interference basis. A limited program was finally initiated near the end of July 1978 to acquire strain sensor data, photographic data, and line load information during the biomass pipe assembly and installation. The program was welcomed and approved by the main Biomass Program Sponsors with the understanding that the pipe instrumentation and data tasks were to be on a strictly no-interference basis with main program operations and/or schedules. Although previous GE experience in ocean data systems permitted a rapid engineering definition of the instrumentation system, only six weeks were available to design the system, procure materials, fabricate/assemble and calibrate the instruments, and ship to the California field site. This was a marginal schedule period for such a program involving hardware acquisition and necessarily limited the scope of design trade-offs and material purchase options due to the extremely short delivery requirements. In view of the non-interference nature of the program, this was accepted as a hard, unalterable schedule constraint.

2.0 PROGRAM CHRONOLOGY

Contract effort was initiated 21 July 1978. Three separate tasks were conducted: (1) Plan, design, and build strain sensor instruments and acquire strain data; (2) Plan and implement photographic data acquisition; and (3) Plan and implement measurement of tow/lowering line tensions. A major field operation occurred 18 September 1978 when strain and photographic data were acquired during a pipe deployment operation which subsequently had to be aborted due to changing weather conditions. Field operations ended 27 September 1978 with acquisition of lowering line tension data during the second and successful pipe installation. A limited in-house data scan was completed in Philadelphia 26 October 1978. A history of program events is presented in the following chronology. A more detailed chronology for events associated with strain instrumentation and data acquisition is presented in Section 3.1.4.

OVERALL PROGRAM CHRONOLOGY

July 21	-	Contract effort initiated.
July 27	-	Helicopter, Photographer, GMDI P.O.'s initiated.
Aug. 2	-	Coordination meeting with GMDI, Newport Beach, California: Instrument compatibility, cable routing, on-board recording, mooring plan, work boat availability.
Aug. 3	-	Briefing of NOAA personnel at GMDI, Newport Beach, California.
Aug. 4	-	Strain harness design completed.
Aug. 7	-	Major harness parts ordering completed.
Aug. 11	-	Dyna-Line tensiometer P.O. initiated.
Aug. 18	-	Major harness parts delivered to Philadelphia.
Aug. 23	-	All shipboard recorders/instruments assembled, calibrated at Philadelphia. Final boat power requirements defined.
Aug. 24	-	Monthly Progress Report presented to NOAA/OOE.
Aug. 28	-	Strain harness fab/cal complete in Philadelphia. All shipboard recorders/instruments received in California.
Aug. 30	-	Strain harness equipment received in California. Review buoy/substrate cable routing/buoy penetration design, and inspect hardware at Bethlehem Shipyard, L.A.
Sept. 5	-	Dyna-Line tensiometer received in California.
Sept. 7	-	Photography coordination/planning meeting at GMDI.
Sept. 8	-	Work boat "Trojan" available for loading instruments.
Sept. 9	-	Instruments loaded on "Trojan", checkout initiated.
Sept. 12	-	Shipboard generator installed on "Trojan", calibration completed at shipyard, Newport Beach, California.
Sept. 14	-	"Trojan" with instrumentation aboard arrives Dana Point Harbor pipe assembly site. First pipe sections fused. Prepare for installation of first strain sensors.
Sept. 15	-	Begin installation of sensor units and cables on pipe. Approximately half of units installed by end of day.

OVERALL PROGRAM CHRONOLOGY (cont'd.)

Sept. 16 - Remaining pipe sections assembled, all but last three sensors installed on pipe.

Sept. 17 - Remaining sensors installed, pipe completed and launched over sea wall into harbor. (See detailed Chronology Section 3.1.4)

Sept. 18 - Final install/checkout on "Trojan" completed (0345)
Helicopter first arrives on site (approx. 0645)
Begin tow to site (0856)
Arrive at farm (1200)
Start pipe deployment operation (1230)
Flood pipe to start sinking operation (1545)
Pipe washed under buoy, harness failures (1604)
Helicopter coverage terminated (approx. 1630)
Abort deployment operation (1730)
Begin return tow with flooded pipe (1800)
Arrive/secure Dana Point Harbor (2100)
(See detailed Chronology Section 3.1.4)

Sept. 19 - Completed preliminary inspection of harnesses

Sept. 20 - Completed pipe damage inspection, made decision to repair before another deployment attempt.

Sept. 21 - Completed final inspection of cable damage. Determined repair not feasible. Identified alternates. Off loaded recording system from "Trojan".

Sept. 22 - Plans for pipe repair completed/approved.

Sept. 23 - Prepared to refloat pipe.

Sept. 24 - Blew water out of pipe, refloated in harbor.

Sept. 25 - Towed pipe out of harbor to turn around, reverse ends. Pulled damaged end up on beach. Decision made not to reinstrument pipe and to remove harnesses and sensors.

Sept. 26 - Pipe repaired, relaunched prepared for tow. Remaining sensors/cables removed.

Sept. 27 - Begin operation/preparations (0000)
Initiate tow (0200)
Arrive farm site, take current readings (0530)
Align pipe in proper sector, initiate operations (0630)
Initiate footpiece lowering/tension measurement (1015)
Complete lowering operation (1115)
Cut lowering line to complete upending (1130)
Initiate raising for mating with buoy (1200)

OVERALL PROGRAM CHRONOLOGY (cont'd.)

Sept. 29	-	Complete hookup to buoy and final mating. Installation complete at 1300 hours.
Oct. 10	-	Set up and calibrate data scan instruments at Philadelphia.
Oct. 11	-	Begin limited data scan-magnetic tapes/movie film
Oct. 26	-	Complete data scan
Nov. 15	-	Complete Final Report
Nov. 16	-	Final Report presentation to NOAA/OOE

3.0 DISCUSSION AND RESULTS

Three independent tasks were accomplished.

- Strain sensor harnesses were designed, fabricated, and installed on the pipe. Data were acquired during the tow and installation operations of 18 September 1978.
- Photographic data were recorded during the pipe assembly and sensor installation operations on the beach at Dana Point, California. Photographic records were also obtained from surface vessels and a helicopter during the installation operations of 18 September 1978.
- Lowering line tensions were measured and recorded during the successful pipe installation of 27 September 1978.

The following subsections describe the instrument systems, measurement techniques and results for the three tasks. Conclusions and recommendations are presented in Sections 4.0 and 5.0 respectively.

3.1 Strain Sensor Data

The basic design was developed during the first week of the program and remained essentially unchanged. The hardware was fabricated, installed and utilized to acquire ocean data on 18 September 1978. On that date, it sustained severe damage during an aborted operation, and after review of several options, was removed from the pipe prior to final installation. The following sub-sections describe the harness design, fabrication, and installation, the 18 September 1978 data acquisition, and a discussion of the results of a limited data scan of the recorded data. A discussion of the damage sustained in the aborted mooring and the rationale for the no-repair decision are also discussed.

3.1.1 Strain Sensor Harness Design/Fabrication

Two harnesses were fabricated with 15 strain transducers on each harness. The system was designed to mount on the outside surface of the upwelling pipe and to measure axial strains in the polyethylene pipe material. The two harnesses were installed on two axial lines along the entire length of the pipe with the two longitudinal rows of sensors displaced by 90 degrees around the pipe circumference. The sensors were distributed uniformly along the length of the pipe except that some were positioned to measure strain across butt-fused joints, at section midpoints, and above/below a wall-thickness transition section. (See Table 1)

3.1.1.1 Harness Cables

The harnesses were fabricated from Spectrastrip 25 Conductor/24 gage ribbon cable with 10 mil PVC insulation. Wire samples were subjected to an underwater pressure test where the test sample was cycled between ambient and 750-1000 psi two times to assure the basic integrity of the insulation, at least for a short time period. After approximately 2 1/2 hours under pressure and two days in an ambient pressure sea water test, no measurable degradation in insulation resistance was noted. In addition, the specimen was high-potted to 2 KV in salt water at 1000 psi with no evidence of insulation breakdown. A more extensive quantitative evaluation and testing of cable insulation were precluded by the extremely tight scheduling. This particular cable was selected because of previous experience at GE with the bonding and potting of urethane to this cable for underwater applications, and the short-term (2 week) delivery available from Spectrastrip in the lengths required. Plans were made to overcoat the cable insulation with 3M Scotch Kote (a liquid PVC compound) to reduce water absorption. Although several different techniques were tried, it was not feasible to apply a coating of acceptable quality within the available time either in the fabrication shop or in the field.

The harnessing was designed such that each cable supplied the needs of fifteen four-wire sensors. In the upper harness section of about 450 feet, fifteen of the 25 conductors were designated as signal leads, 5 as +28 volt D.C. power and 5 as common power and signal ground. At a location near the top of the pipe, the cable was cut. Then, starting at the bottom end of a long (~1400 ft.) piece which would be near the bottom end of the pipe, the cable was cut and stripped in such a way that three wires (power, signal, ground) terminated at each desired sensor location. This provided a harness for eight sensors, all with independent leads. The 22 conductor end of the stripped off "scrap", i.e., that end which had been near the bottom, was then reversed and aligned with the 25 conductor (upper) end of the eight sensor harness. This piece of cable was cut and stripped to provide another independent harness for the remaining seven sensors. The upper 450 ft. piece of 25 conductor cable and the two harnesses were wired together in such a way that each power and ground lead in the upper cable supplied three sensors, i.e., 3 signals, 1 common power, 1 common ground, while all sensor leads were still independent in the lower harnesses. The joint area was potted into a urethane block which could be mechanically fixed to the pipe. This arrangement is shown schematically in Figure 1. In this way, maximum use was made of the available cable, and the number of solder joints was reduced to a minimum.

The cables were fabricated such that 10% slack would result when the sensors were installed at the stations listed in Table 1.

The fabrication of the "B" cable was modified slightly because one length of cable was broken during manufacture and was delivered in two pieces. One piece was 800 feet long and the other was 1200 feet long. The harness fabrication was handled as above except the junction block was located at 1200 feet instead of

1460 feet, and some of the added wires ran upward in the second harness instead of all running downward.

3.1.1.2 Sensor Attachment

The sensors selected for the measurement were DC to DC LVDT's with a ± 0.500 inch stroke, manufactured by Trans-Tek, Inc.

A full description can be found in Attachment 1. The four sensor leads were cut short, stripped, and soldered to the applicable harness leads. The sensor power ground lead and signal ground lead were commoned at this point. The sensors were then clamped to the harness by the mounting clamp as shown in Figure 2. The solder joints and harness wires were then potted to the sensor body (see Figure 2). The opposite end of the sensor body was also potted to preclude the possibility of sea water seeping between the sensor shell and coil spool. As the sensors were attached to each harness, they were identified 1 thru 15 with sensors 15 at the intended top of the array and 1 at the bottom.

3.1.1.3 Calibration

The sensors were individually calibrated by mounting each sensor vertically above an adjustable horizontal platform upon which a 0.500" thick block rested. A core was inserted and was supported by the block and platform. With 28 ± 0.001 VDC applied to the end of the harness, the platform was adjusted until the sensor output was nearly zero. The "zero" output was recorded. Then the block was removed and the output was again recorded. These data are listed in Table 2. The derived position and strain sensitivities are also listed.

After calibration, each core was placed in a bag labeled with the identification of the sensor it was calibrated with. The core cavity of each sensor was then injection filled with silicone grease. The grease would keep sea water out of the core cavity and prevent the accumulation of foreign material which might interfere with core movements. A laboratory test unit was fabricated in this configuration and placed in a salt water bath to obtain information on the effectiveness and potential life of the waterproofing technique. After approximately six weeks (last check) no change in performance had been observed in the test unit output.

During calibration, it was discovered that the three units in a group were inactive. This is apparently caused by the input voltage change at the transducer because of current changes in the common 28 V line as the current changed with each unit's output change. The interaction was significant (several per cent) if one of the units was driven through its maximum current change by completely removing the core from the unit.

If the core movement was limited to the operating range of the unit, the interaction was insignificant (less than 1%). To eliminate the effect during calibration, each sensor sharing the common power leads with the unit under test was adjusted to an output of less than 1% of full scale.

3.1.2 Harness Installation

Figure 2 illustrates the installation details of the LVDT sensor unit. To accomplish the installation, a drill jig was used to provide alignment and location of the four mounting screws. The LVDT body was mounted first. Then the core was screwed into its mounting bracket and the assembly was slid into position and fastened to the pipe. Both LVDT body and core mounting brackets were attached with self tapping screws in blind holes.

Excess grease extruded from the core cavity by the core insertion was wiped away, but leaving a generous fillet of grease between the core shaft and sensor body. Power was then applied to the sensor, and all three sensors in the group were adjusted to zero ± 0.1 volts output. The sensor which had just been mounted was then fine adjusted to zero ± .03 volts and locked. All the screws in the assembly were then "locked" with RTV silicone rubber. In order to provide some protection from flow and other operational hazards, the installation was then covered with a 9", diameter polyethylene fairing held to the pipe with four self-tapping screws.

The pipe was cleaned at five foot intervals with naptha, and the cable was taped to the pipe with two wraps of glass tape covered with four wraps of yellow, vinyl tape. The 10% slack was evenly distributed between the tape wraps. The yellow tape was used along with yellow fairings to enhance photographic visibility and provide reference marks.

Because of variations in pipe section lengths and the desire to bridge pipe joints with some of the sensors, it was not always possible to mount the sensors at the planned stations. The actual sensor locations are listed in Table 1.

The sensors were installed in two rows, located at ± 45° from the top center line of the pipe as it came out of the welding machine. Consistent azimuthal alignment of the sensor rows along the pipe length could not be maintained, however, since the pipe sometimes had a tendency to roll or twist after it passed into the water over the sea wall. Final azimuthal locations can be measured from the photographic data obtained before and during the tow. "A" was -45° looking toward footpiece.

The pipe passed over a set of rollers at the edge of a wall as it went down into the water from the beach assembly area. At low tide, the pipe was about seven feet above the water at the wall and contacted the water at a point about 50 feet from the base of the wall. In passing over the rollers, the pipe assumed a noticeably oval cross section. The output of LVDT B3 was monitored as its section of pipe passed over the rollers and entered the water. The measured strain was + 0.237% (stretch) crossing the rollers and - 0.540%

(compression) entering the water. These measurements were made at low tide. These are the largest strain values seen in any of the data scanned to date.

3.1.3 Shipboard Data System and Data Record Format

A block diagram of the data recording system installed aboard the "Trojan" is shown in Figure 3. Recorders 1, 2, and 3 were 14 channel tape recorders. Recorder 3, as used, had only seven channel capability in the main frame. The other seven channels were available through an additional chassis which was not used in this operation. Voice annotation was recorded on Recorder 1 edge track, and time code was recorded on one data channel of each recorder. IRIG B time code was used. This provided a thirty-two data channel tape recording system. The three chart recorders provided eight additional channels of hard copy data for real-time viewing and evaluation.

The tape recording system was calibrated to record ± 10 volt inputs. Each channel of tape recorders 1 and 2 was adjusted to a 54 KHz center frequency, a ± 40% deviation for ± 10 volts in and for an output of ± 2.5 volts for ± 10 volts in. Each channel of recorder three was adjusted as above except the center frequency was 27 KHz. The calibration of the chart recorders was checked, and did not need adjusting.

On the morning of the tow, -5 volts was sequentially applied to each tape recorder channel (except the time channels) for calibration. Annotation of when the signal was applied to each channel was recorded on the Recorder 1 voice edge track.

Tape recorder channel allocations are listed in Table 3. Chart recorder channel allocations are annotated on the charts.

Tape recorder speeds were set at 15 I.P.S.

3.1.4 Detailed Strain Data Chronology & Events

Assembly of the pipe and instrumentation installation began on Friday, September 15, 1978 and was completed Sunday, September 17, 1978. Sunday afternoon, the pipe was inadvertently moved with an anchor rope still attached. The rope slid and rolled along the pipe for a considerable distance. The sensor harness insulation on both arrays was severely damaged, and the leads were torn out of one sensor in the "A" array near the top end of the pipe.* Repair of this damage which extended over about 30 ft. of cable, required several hours of effort ending at approximately 0030 the morning of the tow. As a result, the mating of the sensor arrays to the data recording system, consequently, was not completed until 0330 hours, September 18, 1978. Spot checks of the recorder channels indicated that the systems had not drifted significantly since they were adjusted several days before; therefore, it was decided that an entire system realignment was not required.

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* Although not specifically discussed, several other instances of cable damage during the assembly/fabrication processes occurred. These were generally caused by normal handling procedures for the pipe and were repaired with field repair techniques used in previous underwater hardware programs. The damage on 17 September 1978, however, was by far the most extensive and difficult to repair.

On September 18, 1978, the following events occurred at the indicated times.

0844 We began the recorder calibrations. To accomplish this, one of the power supplies was disconnected from the "B" sensor array, was adjusted to 5.00 VDC and was connected to a B.N.C. cable as a -5.00 V.D.C. cal signal. Then, starting with Recorder 1, channel 1, the sensor signal cable was disconnected, the cal. cable was connected, the voice track was annotated with recorder and channel number, the cal. cable was disconnected and the sensor signal cable was reconnected. This sequence was repeated, for each recorder channel except those with time code. During the cal. period, the "B" array sensors which would normally have been powered by the power supply being used for calibration were of course not working.

0856 The "Sampson" and "Trojan" began to move the pipe toward the harbor exit.

0858 The calibration power supply was re-installed in the system and power was restored to the effected "B" array sensors. At that time, it was noted that the AC power switch was off on one of the other power supplies. Whether the switch was bumped off during re-installation of the "calibration" supply or was off all morning is unknown. In any event, by 9:15, all supplies were on.

0918 The "Sampson" exited the harbor mouth.

0929 It was noted that Recorder 2 was not operating properly. All squelch lights on the playback boards were blinking. The condition deteriorated rapidly until the lights were constantly lit. The "Trojan" exited the harbor.

0949 Completed a series of tests on Recorder 2 which indicated the record boards were operating properly. Sensor outputs were checked and were nominal. Output boards were not providing meaningful information.

1024 Began to switch sensors from Recorder 2 to spare channels on Recorders 1 and 3 and to activate the standby strip chart recorder. Recorder 2 had failed completely. The tape drive had overheated and failed. We believe the problem was in the tape drive/sync system. If there is any data on tape 2-1, it is probably not at the right frequency (due to improper tape speed) and will be difficult to recover.

1200 The "Trojan" came abreast the mooring site and began applying reverse power.

1206 "Trojan" began backing into the farm sector at full reverse power.

1221 "Trojan" stopped max power backing and began to maneuver into position.

1228 "Trojan" was moored, engines shut down.

1300 The remaining two recorders finished their second reels and the data recording system was shut down. Difficulties were being encountered with lowering preparations and the noise from the 115 volt generator was interfering with communications.

1542 The generator was restarted and the data recording system was turned back on. Sensor/recorder channel relationships had been switched around in an attempt to obtain data from as many sensors as possible. The open top end of the pipe had been lowered to sea level. The pipe was rubbing against the side of a mooring spring buoy.

1546 Time code generator was reset. On turn-on at 1542, it actually set itself to 2050. The exact relationship was 1546:00 = 2054:06.

1546:20 The open top end of the pipe was lowered to approximately ten feet below sea level and began to sink along its length. The pipe immediately went under the mooring buoy due to a shift in current.

1548-1552 The pipe apparently came in contact with the anchor line attachment hardware under the mooring buoy and destroyed the "B" array harness. The "A" array harness was being battered against the bottom of the buoy.

1600 A search for sensors still providing useful information was largely negative. Current measurements on the four power supplies indicated that the harnesses were so badly damaged that it would be impossible to separate valid signals from fluctuating shorts, opens and interactions.

1612 The decision to abort the mission had been made. The recording system was shut down. The generator was stopped. In order to prevent any possible interference by the sensor harnesses with the dangerous job of disengaging the pipe from the buoy, the harnesses were cut where they came aboard the Trojan and cleared from the area.

On September 19, 1978, the sensors and harnesses were inspected. In the buoy area, the harnesses were severed and some of the sensors were completely or partially missing. Outside the impact area, the sensors seemed in good condition. The harnesses, however, had suffered significant damage along almost the entire length. In some areas, the slack had been pulled from several taped sections and was concentrated in a single long loop. In one case, the pulling force had broken the lead wires just outside the potting on the end of the sensor. The exact source of the pulling forces is unknown except that significant pull and stretch could be anticipated if the harnesses snagged on hardware parts during the encounters with the spring buoy. Some cable damage may also have been due to the sustained punishment to which the entire system was subjected, particularly after pipe flooding. The pipe lay awash with waves breaking over and around the cables for a period of 5-6 hours during the installation attempt and on the return tow. Damage was most severe in areas where the harness slid under the tape. In some cases, conductors were broken inside the insulation. In other cases, both conductors and insulation were broken and/or damaged. In any event, the multiple failures observed along the cables caused the harnesses to be suspect at every tape ring and effectively eliminated any hope of salvaging useful lengths of wire or repairing the cables.

3.1.5 Data Record Description

(a) Tape 1-1

Tape recorder 1 functioned well during tape #1 (0830 to 1030). A loose part in the tape guiding mechanism caused the lateral position of the recorded tracks (especially the voice edge track) to be slightly variable. The voice modulation is low and may require additional amplification. There is a damaged (stretched) section of tape just after the calibrations caused by a rewind accident. The duration of the calibration inputs were necessarily very brief resulting in some difficulty in calibrating a readout device.

The data illustrated in Figure 4 were taken from tape 1-1 for the time period the pipe was rounding the sea wall. The strains due to bending the pipe while exiting the harbor and the increased wave motion effects as we cleared the harbor are evident.

Figure 5 illustrates data from the end of tape 1-1 (1030 to 1033). The sensors are all working well.

(b) Tape 1-2 (1053 to 1300)

During this interval, some sensor malfunctions in the "A" harness began to appear. Figure 6 illustrates pipe tension, bending and wave motion as the "Trojan" backed into the farm area and moored to the machinery buoy. Noise spikes such as on the A13 and A12 traces are probably interactive power fluctuations caused by an intermittent in power supplying their stable-mate A5. A list of sensor common power groups is presented in Table 4 and should be very useful in identifying possible interactions. We have concluded that recorder problems are effecting A8, A9 and possibly A6 at this time. By the end of tape 1-2, sensor channels A1, A6, A8, and A9 had probably failed. The other sensors were either working or were recorded on tapes we could not review. No failure analysis has been conducted to define the potential causes of apparent sensor failures.

(c) Tape 1-3 (1542 to 1612)

The time code reading at the beginning of this tape is 2050 but is erroneous. At 1546, the time code generator was reset to the correct time. The relationship is 1546 = 2054:06. Figure 7 illustrates a data sample at the beginning of the tape from some of the sensors on Recorder 1.

(d) Tape 2-1

A playback of this tape showed time code and cal signals were properly recorded, at least at the beginning. We could not find any data. If data is present, its retrieval will require more sophisticated play back equipment than we used for our quick look.

(e) Tape 3-1, 3-2, 3-3

The carrier frequency on this tape is 27 KHz at 15 I.P.S. Our play back equipment was set for 54 KHz and could not provide us with a quick review of these tapes.

(f) Recorder 6 (Millimeter Chart)

This recorder was originally set to record strains on the order of 10% (10V). By 9:53, it was obvious that strains were very low. Therefore, the range was set to a more reasonable value, (.05 volts/cm). At 10:00, the speed was increased to clearly show the wave action. At 10:26, this recorder became the primary and only recorder for sensors A1 and A3 due to Recorder 2 failure. Just after the arbitrary 75 minute mark, sensor A1 signal began to show spikes. At 11:38, that unit had apparently failed and the recorder was switched to B8 which was not being recorded on any recorder. Between 13:00 and 15:42, the recorder was switched to B1 and B2. At 15:49:30, both

B1 and B2 shifted scale (B2 off scale). At 15:51:30, the outputs indicated harness destruction.

(g) Recorder 5 (Inch Chart)

This recorder was activated after Recorder 2 failed and was the primary and only record for B11 and B12 from 11:20 until 13:00. Chart speed was 2"/minute, sensitivity was 0.1 volts/inch. At approximately 12:38, a large swell hit the "Trojan" and progressed along the pipe. We annotated the chart with the words, "Big Wave". The progression of this swell can be followed on the other records. Between 13:00 and 15:42, the recorder was switched to B14 and 15. At 15:49:30, B14 and B15 indicated harness destruction.

(h) Recorder 10 (4 Channel H.P.)

Although this recorder was turned on early on the morning of the tow, it was not again monitored and readjusted until just before 10:00. By 10:10, a sensitivity of 0.05 volts per small division and a speed of 10 mm/min had been selected. Sensors A2, B1, A15, and B15 were being recorded. At 10:30, Recorder 10 became the primary and only recorder for B15, B13, B14 and A2. Just before 11:30, A2 showed anomalous outputs and the recorder channel was switched to B10. Actually, A2 was reacting to the failure of A1. Later, A2 provided good data. At 12:16, the recorder speed was increased to 25 mm/min to better resolve the wave action. We could not increase the sensitivity of the recorder without inducing a servo buzz which resulted in pen/paper writing difficulties. Between 13:00 and 15:42, the recorder was switched to B10, B11, B13, and B12. At 15:49:45, the sensor harnesses were destroyed by buoy impact.

3.1.6 Harness Damage and Termination Decision

As noted above, both harnesses were broken at the point of impact with the spring buoy and very severely damaged for some distance along the cable length in this area. In addition, however, the close post-abort inspection showed that extensive and much more subtle damage had occurred, primarily at the tape rings, over almost the entire pipe length. In some cases, this damage was only detectable by close visual inspection of the cables and consisted of wire breaks inside insulation which was apparently undamaged. Additionally, a complete inspection was impossible since 1,000 ft. of the pipe length remained in the water resulting in certain section of cable being accessible for inspection (or later repair). Under these conditions, the entire length of cable was suspect and was deemed unacceptable for further use.

The first option considered was to obtain new cables, checkout sensors, and reinstall at least one row of sensors. This was not feasible since:

- New cable delivery times were totally incompatible with program schedule.
- The number of field joints and splices required would probably have resulted in unacceptably low hardware reliability.

- Installation of a complete harness was impractical since two thirds of the work would have to be accomplished on the length of pipe section still in the water.

The schedule impact was, by far, the overriding consideration.

A second, less ambitious option was considered. Two 450 ft. lengths of cable (those sections which were originally used to bring the data from the top end of the pipe into the shipboard data system) were available and were probably undamaged. The alternate plan evaluated was to salvage checkout and reinstall several sensors along the top 450 ft. of the pipe using one length of cable as a harness and the second length again to bring data aboard the ship. This approach was also rejected for the following reasons.

- Data during tow and initial farm-situ operations were already available. Primary need for further data was to make strain measurements near the bottom of the pipe during the footpiece lowering. This option could not place sensors below 450 ft. station.
- Again, the entire installation would be made up of extensive field joints and some limited need for working on the pipe in the water was indicated. Poor hardware reliability was again considered a potential problem.
- Minimum estimated turn around time to accomplish this option was estimated at "several days to a week", even assuming 12-hour work days and no significant problems. Compatibility of this delay with the main program schedule was, at best, marginal.

The negative decision was based on a combination of the schedule delay, potential reliability problems and the questionable value of the new data acquired since lower-end measurements were not feasible.

No other viable options could be identified. The accessible sensors were then salvaged as feasible. The cables were removed to avoid potential interference with installation operations.

3.2 Photographic Data

Photographic data were recorded on both 16 mm movie film and 35 mm still slides. Both types of equipment were employed from shore, boat, and helicopter platforms during assembly operations, and during the tow and initial installation attempt of 18 September 1978. No photography was done during the installation operation of 27 September 1978. All of the assembly operations (related to pipe repair), towing and surface-visible installation operations were essentially the same as those photographed on the previous attempt. A total of two hours of 16 mm, silent movie film (four, 30 minute reels, 24 frames per second) were taken. Overhead helicopter coverage of the tow and operations at the farm site comprise almost one entire reel. The other three reels contain coverage shot from various vantage points around the Dana Point assembly site and aboard two vessels on station during the operations. Approximately 160, 35 mm slides were taken from the same locations as the movies, and, in fact, were generally taken at various intervals between movie sequences.

As would be expected, the resolution of the 35 mm slides is superior to that of the resolution in the 16 mm movies. In the case of the slides, even when the camera was far enough away to frame all or almost all of the 1,500 ft. assembled pipe, the yellow, circular flow shields over the sensor stations are usually distinguishable and in many cases, the yellow tape bands spaced at 5 ft. intervals are resolved. With distant (or high altitude) movie views, it was not possible to resolve the flow shields or the tapes, but the pipe curvature could be related to the pipe length of 1,400 ft. to obtain an absolute reference for a quantitative estimate of bending radii. Several views in both movies and slides would permit a quantitative evaluation of the bending radii encountered in going over the sea wall into the water during assembly at Dana Point. The highest strains and sharpest bend radii were encountered during this operation. A time-correlated listing of events documented on the four movie reels is presented in Tables A-4 and A-5 of Appendix A.

3.2.1 Helicopter Operation

The helicopter employed was a Hughes 300, piston-engined machine with only room for the photographer and pilot. The original plan to use a larger turbine-powered, multi-place Hughes 500D had to be changed to accommodate the changing pipe deployment schedule. None of the larger machines were available for the final date of the operation. The smaller machine also made the technical photographic task more difficult since it did not have a cabin-floor port for straight-down shots and had significantly higher noise and vibration levels. Its flight endurance was 1 hour and 45 minutes.

The helicopter initially arrived over the Dana Point area at first light on the morning of the operation. Some initial photographs were taken of the pipe secured in the harbor prior to start of towing operations. The helicopter returned to photograph the tow out of the harbor and was on station taking pictures until the "Trojan" at the trailing end of the tow cleared the breakwater. Adverse lighting conditions (angles and intensity) forced utilization of high speed movie film with somewhat reduced resolution and also limited available viewing angles since it was difficult to see the dark pipe against the dark ocean background even with the yellow markers. During this phase of the operation, the helicopter's altitude was kept relatively high in order to keep the entire pipe in the frame. The bending induced by tow vessels in exiting the harbor is clearly visible and radii are estimated to be 25-30% of the 1,400 ft. pipe length. No kinking or anomalous bending behavior was observed at any time; all observed bends were relatively smooth and uniform.

The helicopter returned several times during the steady tow to the farm site and took pictures from various altitudes and aspect angles. As the day progressed, the lighting conditions improved resulting in better photographic quality. Even at the lower altitudes from the airborne pictures, it is difficult to gain an appreciation for the flexibility of the pipe in riding over the waves and swells during the tow. This quality of the pipe is, however, quite clearly seen in some of the surface camera views.

The helicopter maintained station almost continuously (within its endurance limitations) during the entire afternoon's operations at the farm site. Both 16 mm movie and 35 mm still coverage of all aspects of the installation attempt were obtained including the initial positioning of the pipe, its slow drift toward the spring buoy, its flooding and eventual submergence under the buoy which led to the decision to abort. The helicopter terminated operations late in the afternoon after the abort decision.

In general, the overall behavior of the pipe is clearly seen in the helicopter movie shots but only estimates of curvatures relative to pipe length are possible when the frame shows the entire pipe. In the case of the 35 mm slides, the measurement resolution is somewhat improved since the tapes and flow shield are sometimes resolvable. In many cases, however, the camera angles would cause accurate quantitative analysis to be difficult due to required geometrical corrections.

3.2.2 Surface Camera Operations

Surface camera primary function was to document beach and ocean operations in 16 mm movies and 35 mm slides. Cameras on shore and boats did provide adequate coverage of all aspects of these operations both at the Dana Point site and at the farm site.

Limited film was also acquired which could be analyzed to obtain quantitative estimates of pipe motion during the tow. The lateral oscillations of the pipe, caused primarily by waves and swells arriving at angles off the tow direction, can be resolved from some of the boat photography during the tow. Similarly, the vertical oscillations over the waves are clearly visible in some shots with sufficient resolution to make distance measurements. The analysis would be complicated again, however, by camera angles and in this case also by camera boat motion. It is easily seen that the pipe motion follows that of the ocean surface which on the day of the operation varied between three and six ft. swells with periods on the order of six sec.

It should be noted that serious consideration was given to the feasibility of underwater photography during the operations at the farm site. One of the photographers was equipped with underwater cameras and is a qualified diver. It was decided, however, that in view of the complexity of the operation, the size of the hardware, and the number of lines in the water at any given time, underwater photography presented an unacceptable risk to personnel. This was further justified by the fact that water clarity was relatively poor during the operation so that opportunities for safe and meaningful underwater photography would have been almost nil that day.

3.3 Line Load Data

The original intent of this task was to measure tension loads in tow and tag lines during the tow to the mooring site and to measure tensions in the lowering line attached to the footpiece/pendulum weight during the pipe upending operation. The objective was to provide quantitative data on external loads applied to the pipe which could then be correlated with strains measured/predicted from strain sensor and photographic data.

The final mooring plan as described in Ref. 1 called for mounting of the pipe footpiece (leading end of tow) on a transport barge which also carried the nine ton pendulum weight. The top end of the pipe with the horn assembly (trailing end of the tow) was rigged up out of the water and carried by a line over the "A-frame" boom on the bow of the "Trojan". Because of the complexity of this final rigging configuration and the "hard" connections to the vessels, no reliable way existed to obtain meaningful towing load data.

As shown in Ref. 1, the pipe upending operation also involved a number of load and control lines between which loads were transferred during various stages of the operation. In particular, at the upper, horn end of the pipe, the loads were transferred between a number of synthetic lines and wires ropes during the upending and mating operations. Again, the complexity of the rigging system and the load transfer plan made effective measurement of meaningful line load data infeasible. The rigging configuration at the lower, footpiece end of the pipe, however, involved only a single primary lowering line after the pick of the footpiece and pendulum weight off the transport barge. The initial lift was performed by the crane on the D/B "Sampson" but the load was quickly transferred to the "Sampson's" lowering winch system at a depth of 10 ft. During the remainder of the lowering operation, the weight of both the pipe assembly (PE and steel footpiece) and the pendulum weight was carried by the single winch lowering line from the "Sampson". The lines were arranged such that necessary reaction to any horizontal component of the lowering line tension off the "Sampson" was supplied either by the nylon lowering line off the "Trojan" or, subsequently, by the pipe center cable pulling against the

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Ref. 1 - Pipe Mooring Plan/Procedures by GMDI moored machinery buoy (see diagrams in Reference 1, Sheets VIII, IX - Pipe Upending - Phases II, III).

A three-sheave tensiometer was installed on the "Sampson" winch lowering line approximately 5 ft. in front of the winch payout system. This type of device was selected instead of a load cell to permit tension measurements on a running line. The unit was a Martin-Decker Dyna-Line Wireline Tensiometer Model No. UD-12-RU rigged for the 7/8" IWRC wire used for the lowering line. The rented unit was supplied with a gage readout which was not compatible with timely conversion to chart or tape recording so tension data were read and recorded manually during the lowering operation. The range of the unit was 0-40,000 lbs. with an easily-readable resolution of 200-300 lbs. The readout gage was provided with a damping adjustment which was adjusted such that transient load variations of duration significantly less than a second could be detected.

The line on the payout drum was marked off at 50 ft. intervals with flags to indicate the length of line out as a function of time. During the lowering operation, an observer positioned at the tensiometer readout station recorded time, tension, and line length out. Another observer was stationed at the fairleader where the lowering line turned down into the water approximately 50 ft. forward of the winch station. The second observer recorded time, cable footage and estimated (visual) lowering line angle. The arrangement of winch, fairleader, etc., on the "Sampson" is shown in Reference 1.

No tensiometer data were taken on the first installation attempt of 18 September 1978 since the operation was aborted prior to initiating bottom-end lowering operations. A complete set of tension readouts was recorded on the successful operation of 27 September 1978. The results are presented in the chart of Figure 8 which shows tension, line angle, and time from start of lowering as functions of length of line deployed. It is seen that the average values of tension held at around 17,000-18,000 lbs. during most of the one-hour lowering operation. Variations were generally on the order of ± 2,000 lbs. with a few larger variations of up to ± 10,000 lbs. observed with passage of unusually large swells or with "jumping" or slipping of individual cable turns on the payout drum. Fluctuation periods of two seconds were "typical". The transient tension excursions observed had no detectable effect on the overall smoothness of the lowering operation. The final "holding" tension at the end of the payout, prior to cutting the lowering line to complete the upending operation, was 11,000 ± 500 lbs. Line angles (0° referenced to vertical) during the operation varied from 0° at the initial lowering, to a maximum value of 25°. The line angle rapidly reached 15° - 20° shortly after the start of the operation. There appears to be no clear correlation between tension and line angle but it could easily be masked by the transients in the tension data.

4.0 CONCLUSIONS

The scope of the present effort was limited to design of data system and acquisition of strain data, photographic data, and loads data during the assembly and deployment of the upwelling pipe for the Marine Biomass Test Farm. The following conclusions are based on experiences with the planning, design, implementation, and operation of the data systems and also on results of a limited sampling of some of the data after the field operations.

4.1 Strain Measurements

1. The overall strain data system performed well.
2. Significant data on PE pipe strains were acquired during assembly and ocean operations.
3. The largest strain value reduced from the data was 0.54% going over the sea wall. Data sampled from tow and ocean operations are significantly below that level.
4. The DC - DC LVDT is ideally suited as a strain sensor in this application and exceeded the required dynamic range.
5. The 10% strain capability of the system was not required. Both LVDT sensitivity and cable slack requirements could be safely modified for max strains of 2% or 3% with significant margin still remaining.
6. Major data system failure was caused by severe pipe impact(s) with spring buoy at the farm site.
7. This system, cables in particular, was vulnerable to rigors of marine operations and associated rough handling.
8. This system, in spite of vulnerability, was easily repaired in the field for limited damage.
9. An armored cable system would probably have suffered similar but more limited damage, but would not have been as easily field reparable.

4.2 Photographic Data

- Movie and slide film were acquired to provide adequate documentation of all above-water operations.

- Estimates of pipe curvature radii are possible from the films.

- Minimum bending radii observed during tow and ocean operations were about 175-200 pipe diameters. A more severe bend occurred in going over the sea wall during assembly but no quantitative estimate was made from the films.

- The tape system employed to enhance photographic visibility was marginal for 16 mm helicopter photography techniques employed. Sufficient resolution is probably obtained with 35 mm film but further analysis is required.

- Early morning lighting conditions were poor for overhead photography of the black pipe against the sea background.

- The small Hughes 300 helicopter had significant drawbacks as a technical photographic platform in this application.

4.3 Line Load Data

- The Dyna-Line tensiometer provided a useful tool for the required tension measurements.
- Adequate line-load and line-angle data were acquired.
- Line loads and angles were easily maintained within ranges specified in the mooring plan.
- Large transients in tension were observed due to sea motion and cable adjustments on the winch drum. These had no measurable effect on the lowering operations.
- No clear correlation between line tension and lowering angle was found.

5.0 RECOMMENDATIONS

The following recommendations are made based on the results and conclusions noted above:

5.1 Strain Measurements

- No further analysis of present data is recommended except possible correlation of measured strains with pipe bend geometry estimated from photos and/or estimating wave shapes.
- Install systems of this type in future PE pipe deployment operations to monitor strain levels.

- Future systems for PE pipe applications should be designed for much less than the 10% strain capability built into this system.

- Future systems should be designed for installation inside the pipe if at all possible. An alternative approach might be to develop a "hardened", externally-installed system to increase probability of survival under the extreme handling conditions, but this is not an easy task since adequate "hardening" could easily alter the basic strain properties of the pipe.

- Several more detailed hardware related recommendations are:
  - Continue the use of mechanically - fastened DC - DC LVDT's as strain sensors in these applications.
  - Eliminate common power or ground leads to sensors, if possible, to avoid interactions if channels fail.
  - Minimize slack in cabling to be consistent with requirements of reduced strain levels.

- Provide significantly increased lead time for procurement and installation of systems of this type.

5.2 Photographic Data

- Perform limited additional data analyses to obtain estimates of pipe curvature over sea wall and verify existing estimates from helicopter shots.

- Employ helicopter photography in future pipe deployment operations.

- In future operations, provide for longer term commitment of larger turbine-powered helicopter. Aircraft should be capable of carrying photographer and technical observer, provide for straight-down photographic shots and carry RF compatible with vessel communication.

- Recommendations for improving detailed technical quality of photographic data are:

    - Increase emphasis on 35 mm stills versus 16 mm movies to improve resolution for quantitative analyses. If pipe motion data is of primary interest, rely on sequences of rapid stop-action 35 mm stills rather than "continuous" 16 mm movies.

    - Take advantage of improved helicopter capability noted above for straight-down shots where possible.

    - Provide for pre-operation test flight to "calibrate" photographic conditions from helicopter. Critical lighting aspect-angle, and target visibility should be evaluated prior to definition of final photographic plan.

5.3 Line Load Data

- No further analysis of available data is recommended.
- Continue use of 3-sheave tensiometer device for line load measurements of this type in future operations.
- Provide for automated strip-chart recording of output readings.

TABLE 1

STRAIN SENSOR LOCATIONS

NOTE: Stations in feet from top end of first pipe section.

	PLANNED LOCATION		ACTUAL INSTALLED LOCATION	
SENSOR I.D. NO.	ROW A	ROW B	ROW A	ROW B
15	50 FT.	50 FT.	50 FT.	50 FT.
14	150	100	150	100
13	250	200	250	200
12	390	300	390	300
11	420	330	420	330
10	550	490	550	490
9	630	600	630	600
8	740	700	742.75	700
7	850	800	855	800
6	950	900	955	900
5	1,050	1,020	1,055	1,020
4	1,080	1,110	1,080	1,109.6
3	1,150	1,200	1,150	1,200
2	1,250	1,300	1,250	1,300
1	1,370	1,370	1,370	1,370

TABLE 2

SENSOR CALIBRATION

(+ strain (stretch) produces decreasing output.)

SENSOR	"0" OUT	0.5" OUT	VOLTS/INCH	% STRAIN/VOLT
A15	+ .007	- 14.968	- 29.95	- 0.835
B15	000	- 14.119	- 28.238	- 0.885
A14	+ .003	- 14.862	- 29.73	- 0.841
B14	000	- 13.826	- 27.652	- 0.904
A13	- .002	- 14.467	- 28.93	- 0.864
B13	+ .004	- 14.167	- 28.342	- 0.882
A12	+ .008	- 14.512	- 29.04	- 0.861
B12	+ .006	- 14.328	- 28.668	- 0.872
A11	- .009	- 14.463	- 28.91	- 0.865
B11	+ .006	- 13.687	- 27.386	- 0.913
A10	- .007	- 14.313	- 28.61	- 0.874
B10	- .006	- 13.762	- 27.512	- 0.909
A9	+ .001	- 14.277	- 28.556	- 0.875
B9	- .003	- 13.748	- 27.490	- 0.909
A8	+ .001	- 13.900	- 27.802	- 0.899
B8	+ .001	- 13.552	- 27.106	- 0.922
A7	+ .007	- 14.123	- 28.26	- 0.885
B7	- .006	- 13.357	- 26.702	- 0.936
A6	+ .002	- 13.635	- 27.274	- 0.917
B6	- .003	- 13.414	- 26.822	- 0.932
A5	- .005	- 13.780	- 27.55	- 0.907
B5	+ .006	- 13.700	- 27.412	- 0.912
A4	000	- 13.698	- 27.396	- 0.913
B4	+ .006	- 13.011	- 26.034	- 0.960
A3	- .006	- 13.696	- 27.38	- 0.913
B3	+ .005	- 13.200	- 26.41	- 0.947
A2	- .007	- 13.390	- 26.766	- 0.934
B2	000	- 13.317	- 26.634	- 0.939
A1	- .002	- 13.592	- 27.18	- 0.920
B1	000	- 13.045	- 26.090	- 0.958

TABLE 3

TAPE RECORDER CHANNEL ALLOCATIONS

RECORDER	CHANNEL	0830 TO 1300 HRS. SENSOR (OR FUNCTION)	1542 TO 1600 HRS. SENSOR (OR FUNCTION)
1	Edge A	Voice	Voice
1	Edge B	Blank	Blank
1	1	A5	A5
1	2	A6	A6
1	3	A7	A7
1	4	A8	A8
1	5	A9	A9
1	6	A10	A10
1	7	A11	A11
1	8	A12	A12
1	9	A13	A13
1	10	A14	A14
1	11	A15	A15
1	12	B9	B9
1	13	A4 (after 10:24)	A4
1	14	Time Code	Time
2	Edge A&B	Blank	-
2	1	A4	-
2	2	A3	-
2	3	A2	-
2	4	A1	-
2	5	B15	-
2	6	B14	-
2	7	B13	-
2	8	B12	-
2	9	B11	-
2	10	B10	-
2	11	B8	-
2	12	B7	-
2	13	B6	-
2	14	Time Code	-
3	1	B1	B7
3	2	B2	B8
3	3	B3	B3
3	4	B4	B4
3	5	B5	B5
3	6	Blank	B6
3	7	Time Code	Time Code

TABLE 4

SENSOR COMMON POWER GROUPS

GROUP #	SENSORS IN GROUP
1	A1, A2, A15
2	A3, A4, A14
3	A5, A12, A13
4	A6, A7, A11
5	A8, A9, A10
6	B1, B2, B15
7	B3, B4, B14
8	B5, B12, B13
9	B6, B7, B11
10	B8, B9, B10

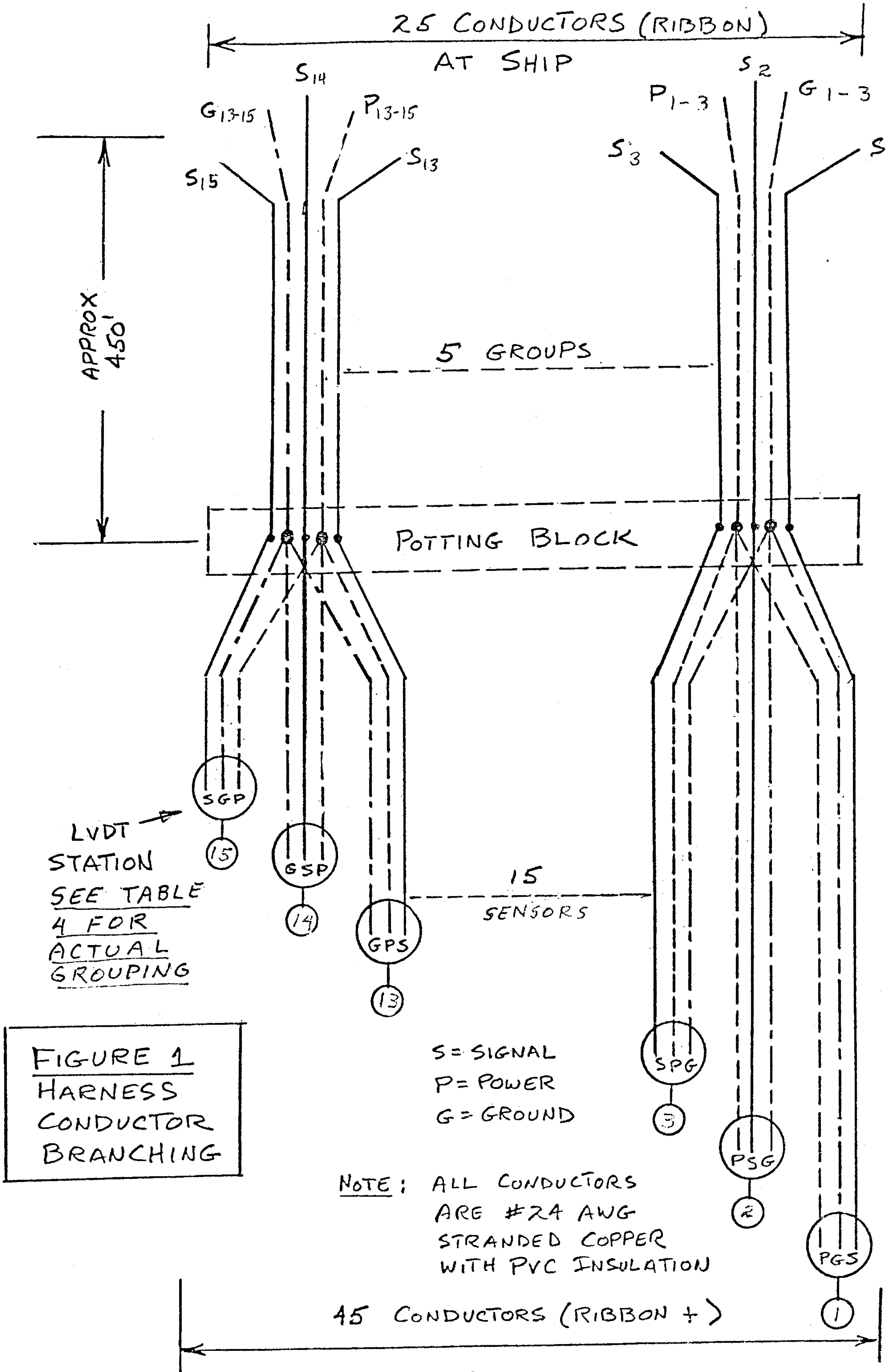
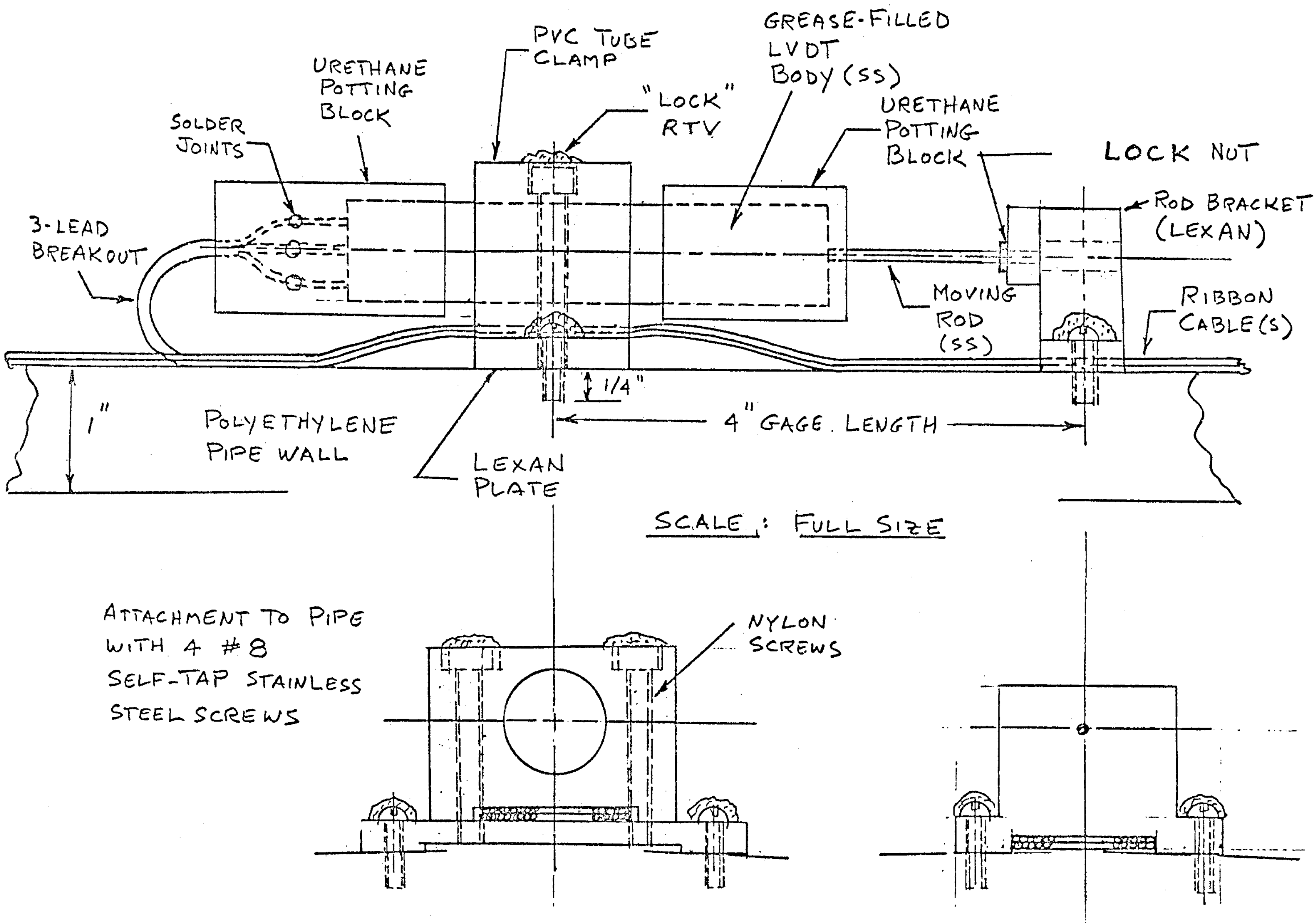


FIGURE 1
HARNESS CONDUCTOR BRANCHING

FIGURE 2 - TYPICAL LVDT INSTALLATION



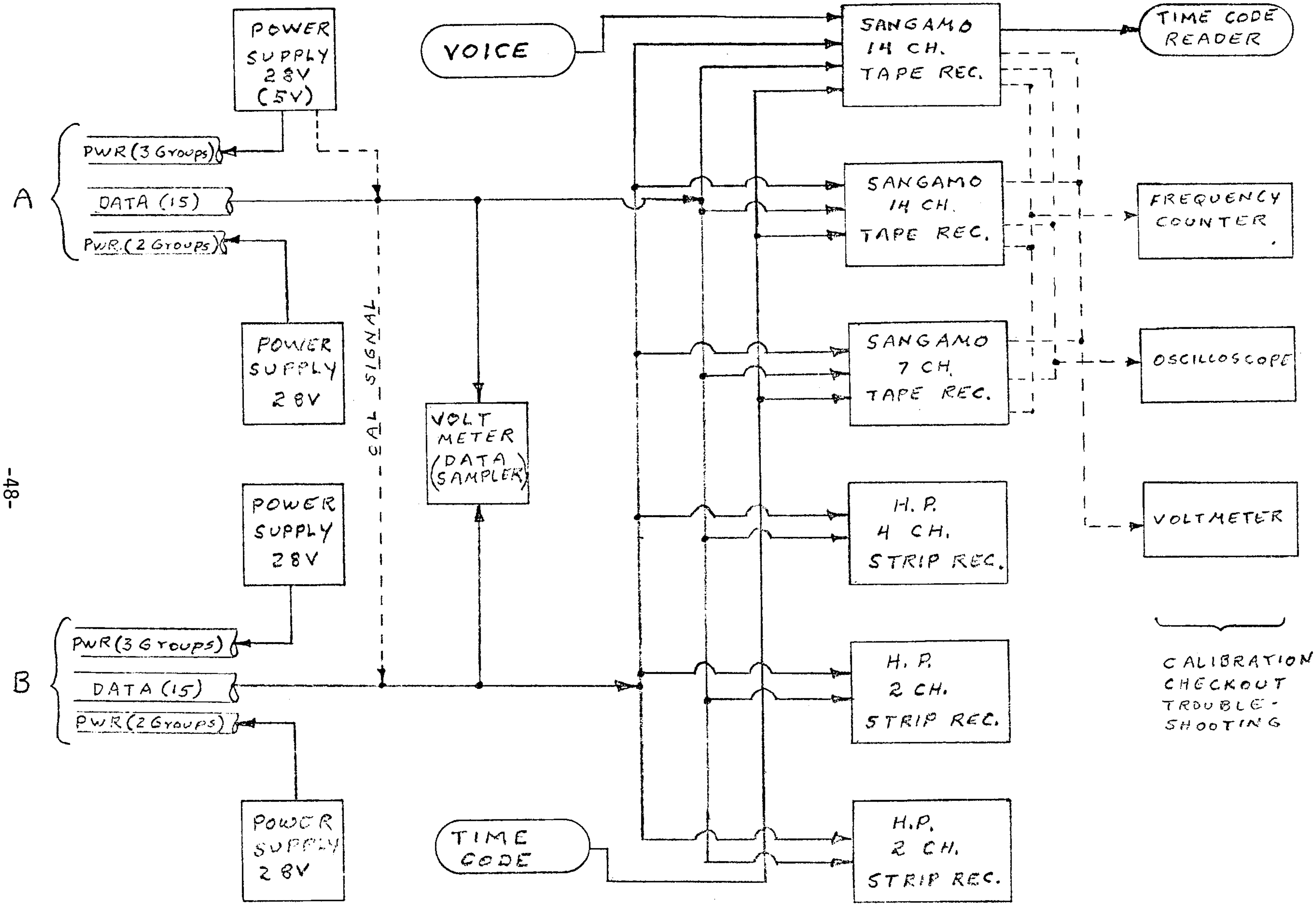


FIGURE 3 - SHIPBOARD DATA SYSTEM

Figure 4 - LVDT OUTPUTS

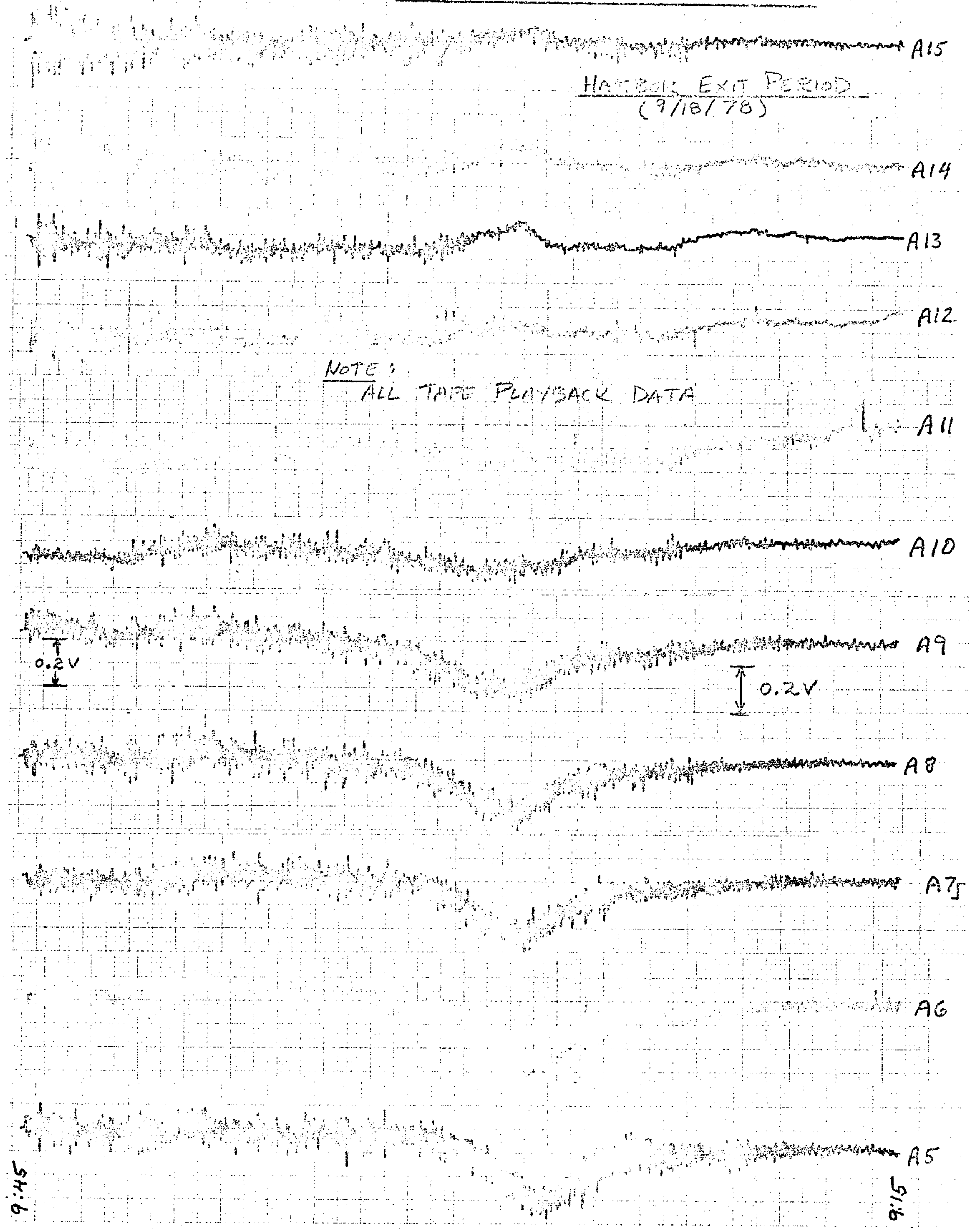
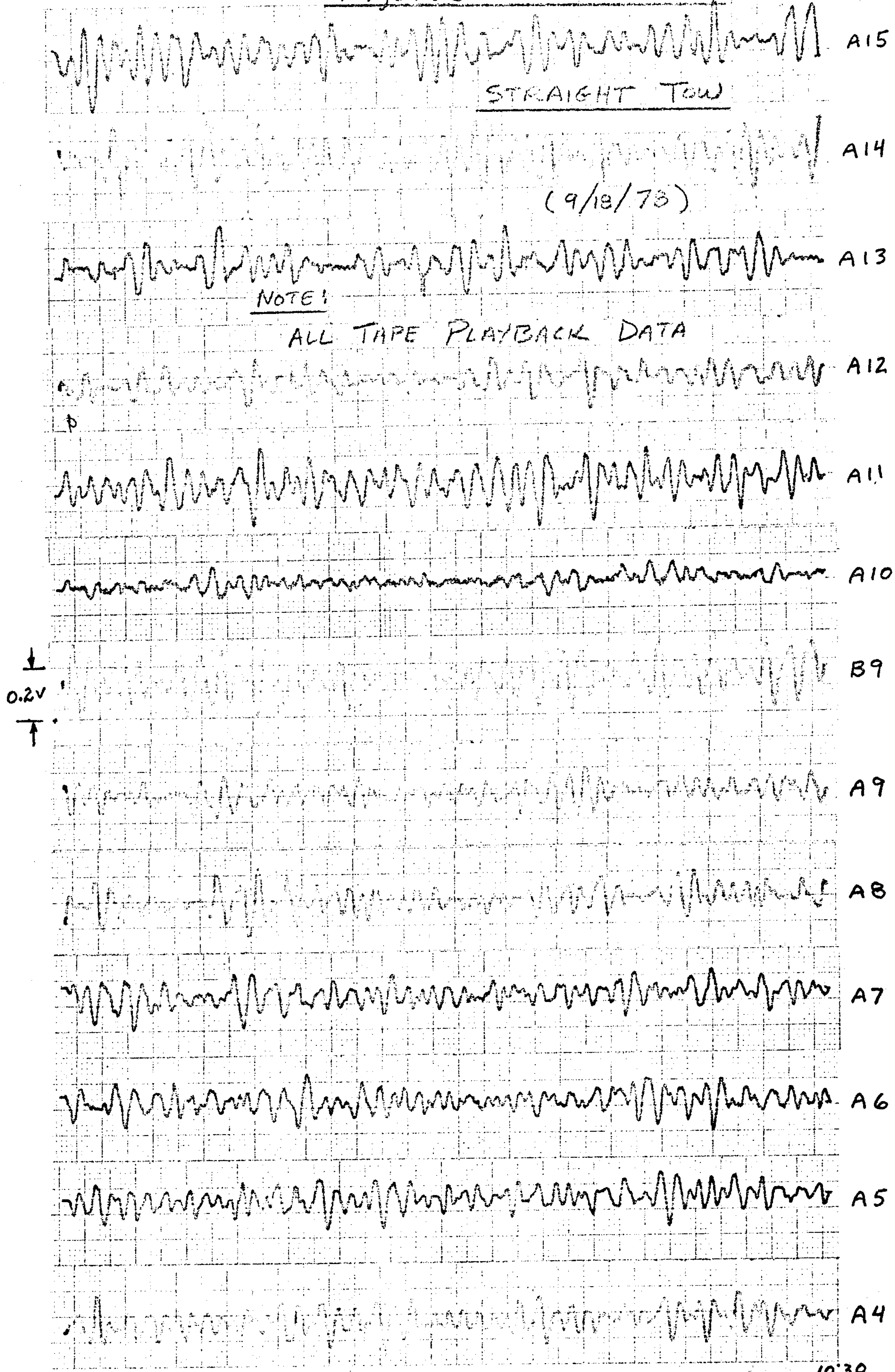


Figure 5 - LVDT OUTPUTS



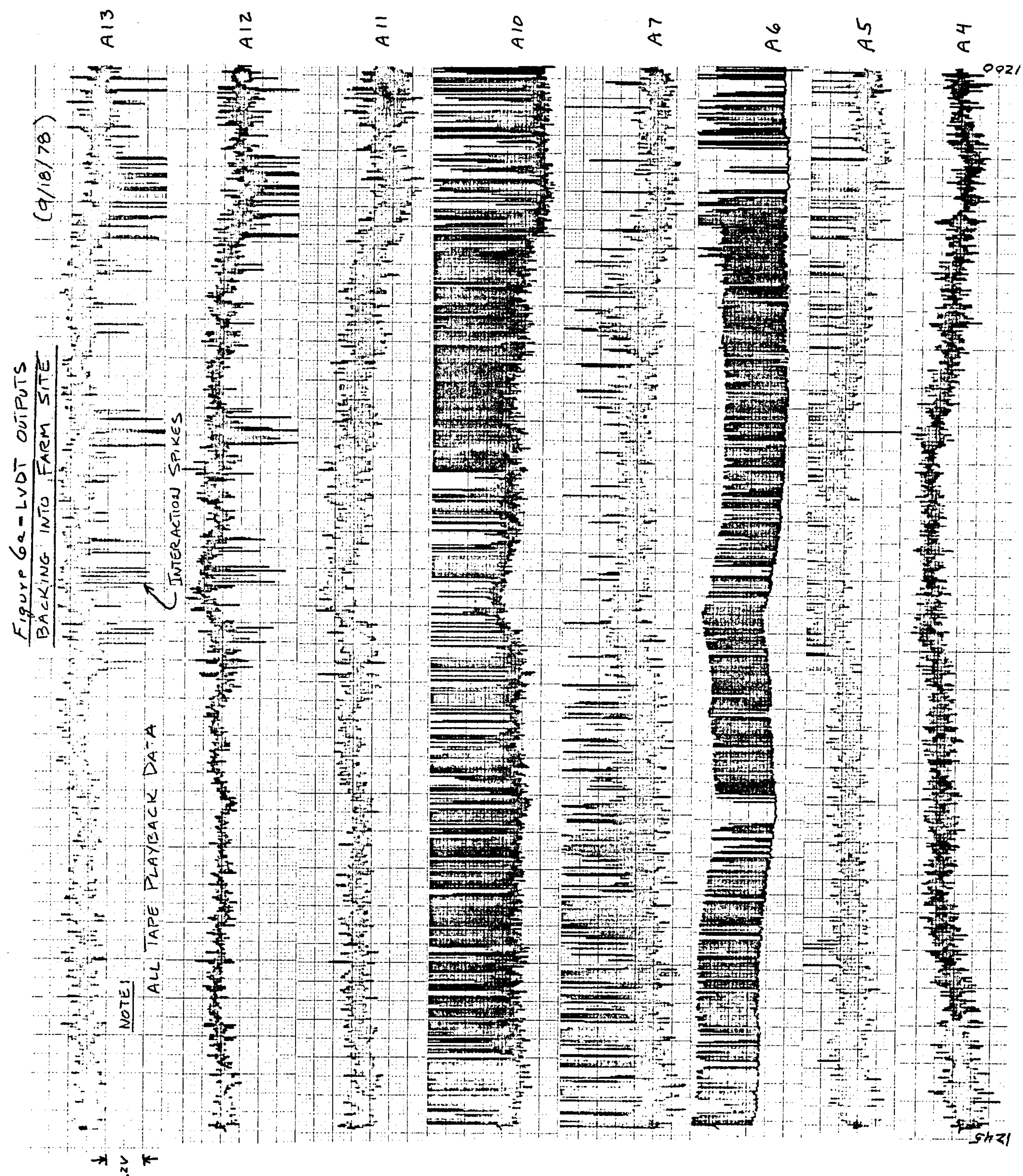


Figure 6a - LVDT OUTPUTS
BACKING INTO FARM SITE
(9/18/78)
NOTE: ALL TAPE PLAYBACK DATA
INTERACTION SPIKES
A13
A12
A11
A10
A7
A6
A5
A4
0921
1245
0.2V

Figure 6b - LVDT OUTPUTS
BACKING INTO FARM SITE (9/10/78)

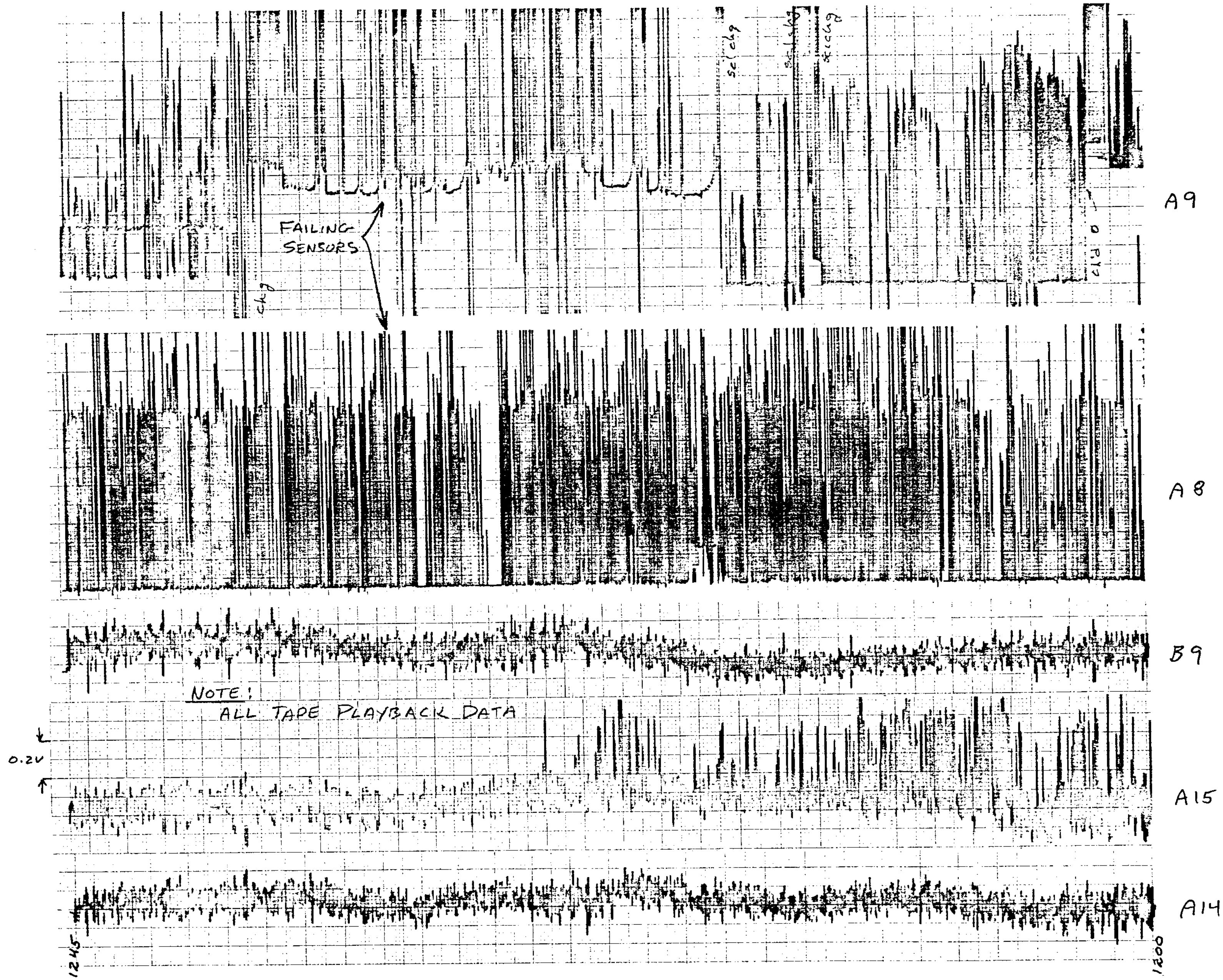
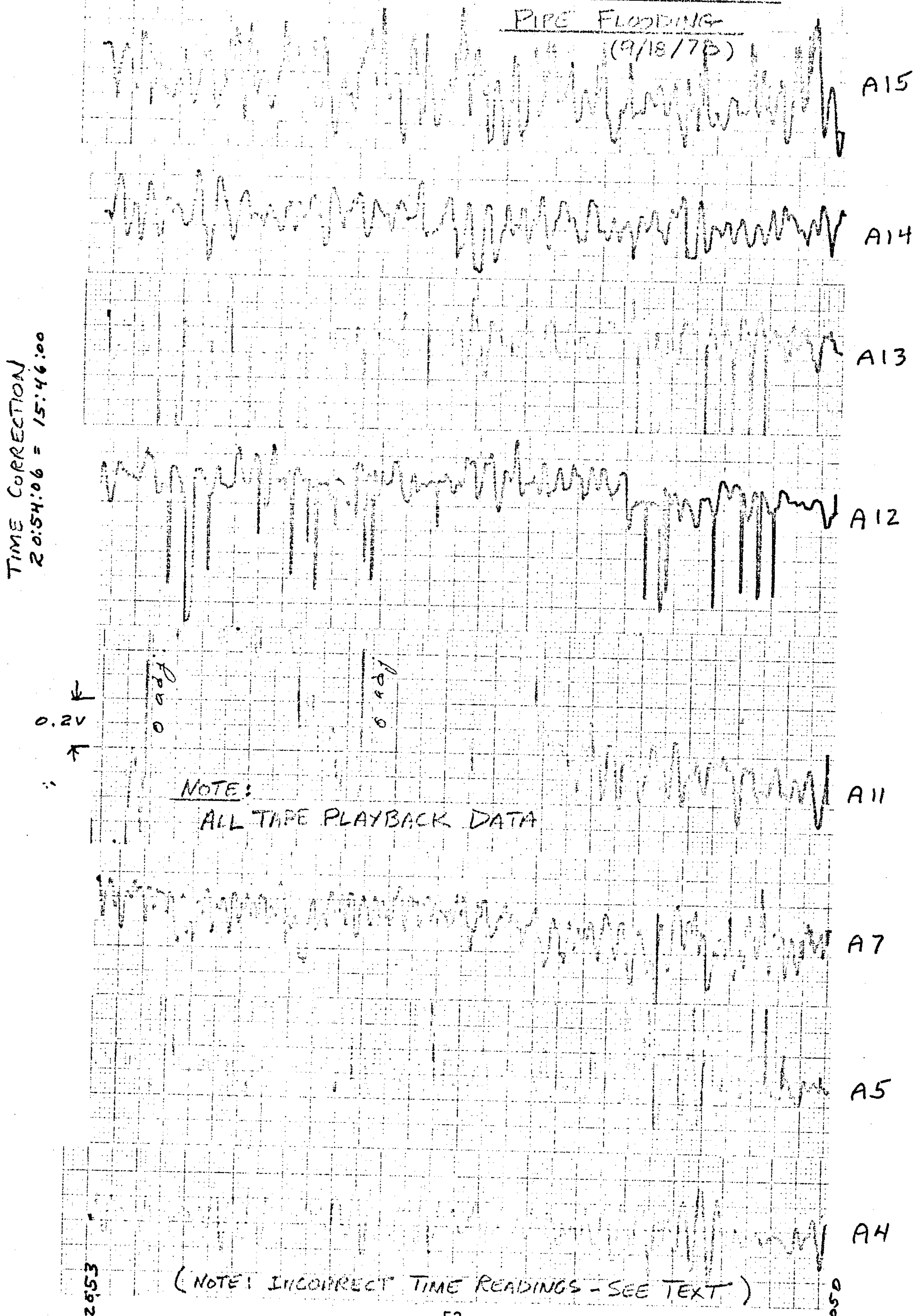


Figure 7 - LVDT OUTPUTS



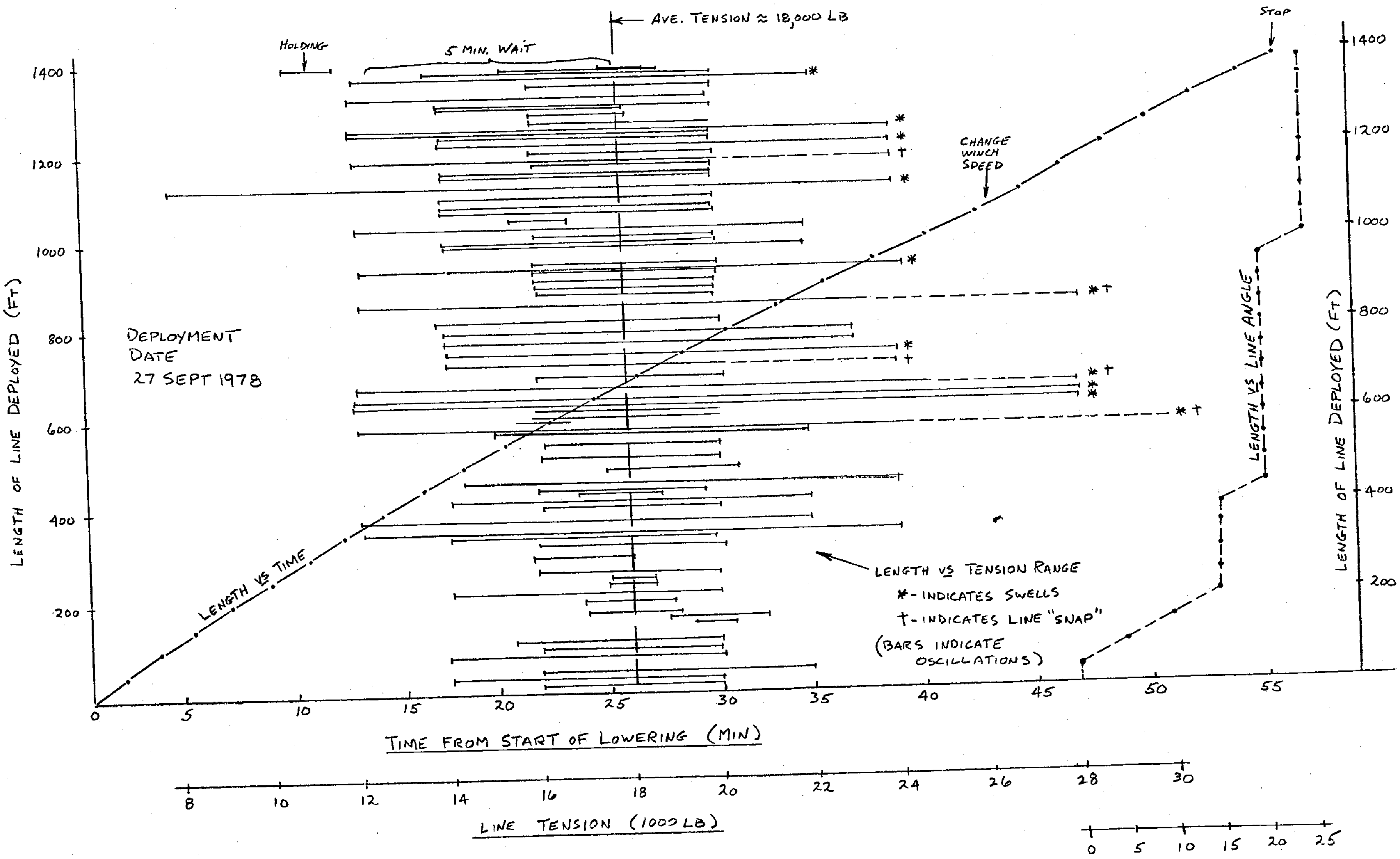


FIGURE 8 LOWERING LINE DATA

Appendix A - Data Recording Events/Chronologies

During the limited data scan, events as verbally annotated on voice tracks of magnetic tapes 1-1, 1-2, and 1-3 were documented in Tables A-1 - A-3. The tables also indicate the approximate footage from the start of the tape to the indicated time/event. No voice tracks were recorded on the other data tapes (Recorders #2 and #3) which were recorded simultaneously with the Recorder #1 tapes.

A review of the events on the 16 mm movie film was also conducted. The events on the films are logged in Tables A-4 and A-5 for the Lambert (outside vendor) and GE (Company photographer) reels. The time (minutes:seconds) of each event from the start of the reel is also indicated. The film speed is 24 FPS.

TABLE A-1

Distance from Tape Start (Approx.)	Time (Local)	Magnetic Tape 1-1 Voice Track Chronology for 9/18/78 — Event
40 Ft.	0323:	- Pre tow cals in progress (night)
80	0844:52	- Start, AM cals before initiating tow (these continue for several minutes)
950	0856:	- Tow started
	0858:	- All sensors recording
1350	0901:	- Mixup on channels being recorded
2120 2350	0912: 0915:	- Power supply #3 not turned on, Check channels effected
2580	0918:	- Lead end of pipe clears jetty
3354	0929:	- Trojan clears end of jetty. Also note problems with Recorder #2.
4900	0949:17	- Do not know whether Recorder #2 is recording data or not. Problems with mainframe and tape drive. Will not fix.
	1016:12	- Tow/sea state information: Tow speed ~3 kts, wave height ~6 ft., period ~6 sec.
7500	1024:21	- Switched channels around - put A4 sensor on channel 1-13.

TABLE A-2

Distance from Tape Start (Approx.)	Time (Local)	Magnetic Tape 1-2 Voice Track Chronology for 9/18/78 Event
25 Ft.	1053:45	- Time code data present, start recording (no voice)
5200	1202:50	- Pipe tow arrives at site, stopping motion
5352	1204:58	- Trojan begins backing hard to reverse tow. Not sure whether D/B Sampson has stopped all pulling on opposite end.
5490	1206:45	- Trojan starts backing into farm sector. Max. reverse, should be considerable tension in pipe now.
----	1218:35	- Trojan approaching mooring buoy, backing at max. power.
----	1221:47	- Trojan at mooring buoy, stops backing, begin maneuvering over to machinery buoy.
----	1228:39	- Trojan tied now to both mooring buoy and machinery buoy.
----	1233:38	- Waiting for wind/sea to straighten pipe in proper direction prior to beginning installation operations.
----	1238:18	- Big wave noted running down pipe.

End of Tape 1-2

TABLE A-3

Magnetic Tape 1-3 Voice Track Chronology for 9/18/78

Distance from Tape Start (Approx.)	Time (Local)	Event
332 Ft.	1546:01	- Time code data present, start recording (no voice)
350	1546:20	- Note rearrangement of recorder channels to "afternoon" list due to failure of Recorder #2. Begin flooding horn-end of pipe. Pipe begins to sink.
1050	1555:55	- Pipe under mooring buoy, sensor array "B" apparently fails.
1700	1604:00	- Losing remaining sensors rapidly. Probably none of remaining sensors are giving reliable data.
2340	1612:47	- Terminate strain requirements, shut down all equipment.

TABLE A-4

LAMBERT FILM EVENTS (Beach & Helio)

Reel #	Time from Start	Event/Comment
1	0:00	Footpiece mating at Dana Point (9/15/78)
	4:15	Close up of strain sensor installation
	5:20	Lift footpiece over sea wall, install on transport barge.
	9:40	View of pipe with strain sensors, cables, tapes being fed over sea wall in preparation for next butt fusion.
	11:26	Method of pipe payout control using winch truck
	12:20	Preparation for next fusion at machine
	13:10	Aerial from helicopter, early morning views in Dana Point Harbor 9/18/78
	15:10	Start tow
	16:40	D/B Sampson at second jetty dogleg
	20:00	D/B Sampson abeam end of jetty on inside
	21:00	D/B Sampson begins turn to seaward
	21:40	Pipe mid point abreast end of jetty on inside
	22:50	D/B Sampson almost completes turn to NW.
	23:51	Pipe in "S" curve, probably max bending for this part of operation.
	24:46	Trojan passing end of jetty on inside, D/B Sampson has straightened pipe by turn to less northerly direction.
	26:39	Trojan abeam end of jetty heading seaward
	28:40	D/B Sampson turning to more northerly heading
	29:45	Steady, open-ocean tow established

Table A-4
Lambert Film Events (Beach & Helio)
Page (2)

Reel #	Time from Start	Event/Comment
1	30:40	Closer view of pipe under steady tow
	31:30	Continue pipe under steady tow
	34:30	End of Lambert Film (1)
2	0:00	Start with pipe in steady, straight tow
	1:30	Closer shot of pipe in steady tow showing strain sensors and tape markers
	3:42	Closeup of Trojan showing horn, rigging and instrument cables coming aboard.
	4:45	Start closeup run along pipe length
	5:37	Closeup of transport barge and footpiece end
	5:40	Approaching and passing test farm buoys
	9:15	Tow stopped, Trojan begins backing into farm sector for pipe installation operation
	10:40	Pipe bends entering farm sector clearly visible
	11:27	Probable max bend in pipe for this part of operation; Trojan approaches mooring buoy to put on a breast line
	12:50	Pipe bend decreasing, Walrus controlling barge
	14:10	Trojan moored to machinery buoy, pipe fairly straight at this point in time
	14:40	Pipe starts to drift noticeably toward buoy.
	16:25	Pipe about 80-100 feet from mooring buoy
	17:15	Closeup of Trojan, Horn, machinery buoy
	18:07	Pipe within 20 feet of mooring buoy
	20:15	Closeup run along pipe from foot-to-horn
	21:14	Pipe seen apparently against buoy
	22:09	Closeup of pipe against buoy

Table A-4
Lambert Film Events (Beach & Helio)
Page (3)

Reel #	Time from Start	Event/Comment
2	22:20	Initiate flooding of pipe from horn end
	23:10	Pipe apparently under mooring buoy
	23:30	Attempt to pull pipe away from buoy, large bend in pipe apparent
	24:30	Probably max bend in pipe for this part of operation
	25:10	View of entire pipe flooded and awash
	25:49	Sampson attaches to pull pipe off buoy
	26:49	Mathilda/Trojan pulling on pipe
	27:20	Closeup run along submerged pipe
	28:40	End-on view showing pipe bending around buoy
	29:15	End of Lambert Film (2)

TABLE A-5

GE FILM EVENTS (Beach & Boat)

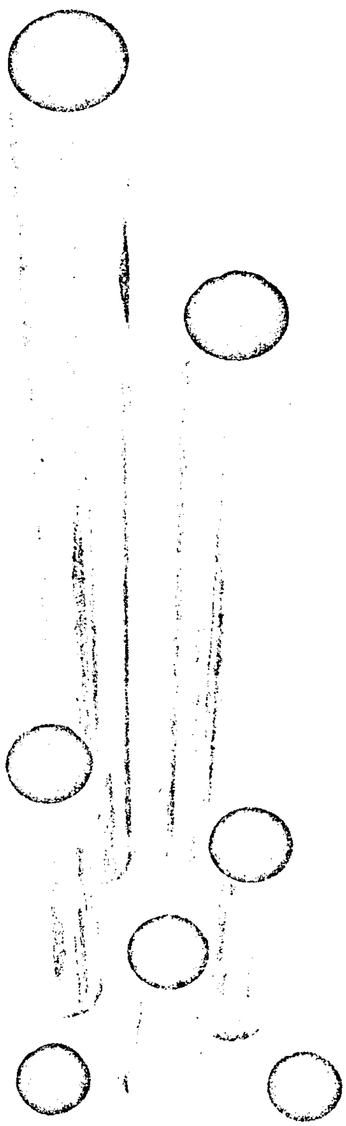
Reel #	Time from Start	Comment/Event
1	0:00	Start with Dana Point pipe assembly, general shots
	1:15	Lifting footpiece over sea wall, start of pipe fabrication
	1:45	Fusing operation
	3:26	View from top of cliff showing pipe shape over sea wall
	5:10	Closeup of pipe, harness, tapes being rolled out over wall
	5:40	Transport barge and view of pipe from barge
	6:10	Closeup view of pipe in harbor from skiff run
	8:20	Joining operation procedures/other beach activity
	17:20	Closeups of sensors, installation of cables, etc.
	23:30	Upper-end stub flange and assembly of horn components
	28:00	Views of almost entire pipe in harbor (from island)
	30:00	Pulling center cable through, view from beach end
	31:00	Preparing to lift horn over sea wall, final assemble of horn and center-cable operations
	34:00	End of Reel #1
2	0:00	Horn being lifted over sea wall
	0:30	Repairing damage to sensor cables
	1:30	Horn-end on pontoon
	3:00	Horn on beach (second camera view)
	4:30	Horn being lifted over sea wall (second camera view)

Table A-5
GE Film Events (Beach & Boat)
Page (2)

Reel #	Time from Start	Comment/Event
2	5:45	Set up start of tow from Sampson
	7:30	At farm site
	8:25	Tow out of harbor (second camera)
	9:10	Views from farm site (second camera)
	11:15	Harbor views before tow (another camera)
	12:50	Begin tow out of harbor
	19:45	Views of helicopter from "Sampson"
	20:50	Arrive at farm site
	24:30	Views of pipe lying near farm buoys
	25:30	Preparation on transport barge
	27:15	Views of boat motion
	28:20	Towing flooded pipe back to Dana Point Harbor
	30:00	End of Reel #2

ATTACHMENT 1

DISPLACEMENT TRANSDUCER DC-DC SERIES 240
3 TO 30 VOLT EXCITATION



FOR A DC VOLTAGE OUTPUT PROPORTIONAL TO DISPLACEMENT

- ☐ DC in, DC out
- ☐ Adjustable scale factor
- ☐ No phasing, harmonic or quadrature null problems
- ☐ Polarity protected
- ☐ Zero hysteresis
- ☐ Stepless output
- ☐ Excellent repeatability
- ☐ High output
- ☐ Up to 8″ range
- ☐ Extreme linearity
- ☐ Fast response
- ☐ Light weight

DESCRIPTION

The Trans-Tek Series 240 displacement transducer is an integrated package consisting of a precision linear variable differential transformer, a solid state oscillator, and a phase-sensitive demodulator.

The transducer is designed to combine in one small but rugged package the achievement of excellent linearity, infinite resolution, and high sensitivity. The phasing, quadrature null and harmonic problems often experienced with AC differential transformers are eliminated.

Input and output circuits are electrically isolated from each other and from the coil assembly housing, making them usable directly in floating or ground return systems. DC indicators, recorders, and control systems can usually be driven directly by the large DC output. The core, when displaced axially within the coil assembly, produces a voltage change in the output directly proportional to the displacement.

PRINCIPLE OF OPERATION

The oscillator converts the DC input to AC, exciting the primary winding of the differential transformer. Voltage is induced in the secondary windings by the axial core position. The two secondary circuits consist of a winding, a full-wave bridge, and an RC filter.

The circuits are connected in series opposition so that the resultant output is a DC voltage proportional to core displacement from the electrical center. The polarity of the voltage is a function of the direction of the core displacement with respect to the electrical center.

CONSTRUCTION

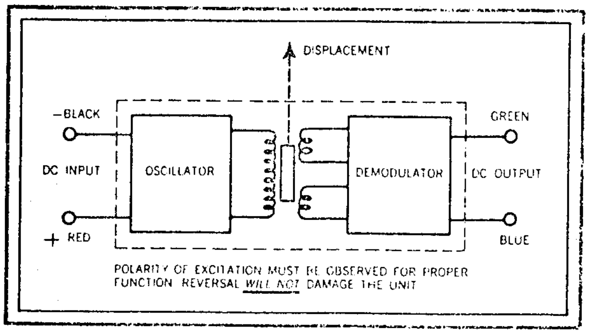
All materials have been selected carefully to achieve optimum performance. The stainless steel housings, coil assembly, oscillator-demodulator, and Teflon-insulated leads are carefully encapsulated in epoxy resin. Oscillator-demodulator components are individually selected to assure accuracy and reliability.

APPLICATION

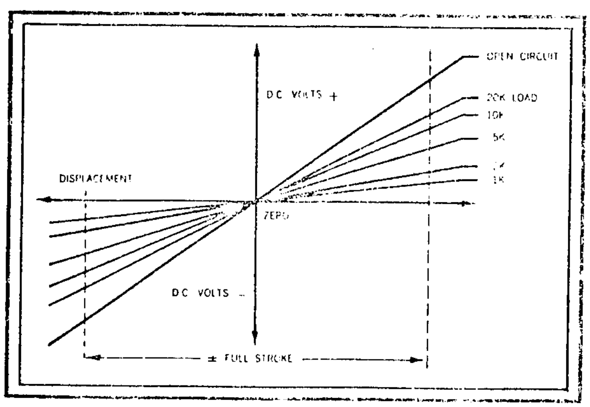
A Series 240 transducer can be used to measure physical functions which can be translated into a linear displacement. Typical applications include servo position feedback, sensor for pressure transducers, strain measurement in structural members, automatic gauging, and machine control.

INSTALLATION

A Series 240 transducer can be mounted by clamping around the housing to a physical reference point. The dynamic member to be monitored is coupled to the threaded connecting rod of the core assembly or to the optional core by means of a threaded extension rod. Mounting hardware should be of nonmagnetic materials such as brass, aluminum, or 300 series stainless steel.



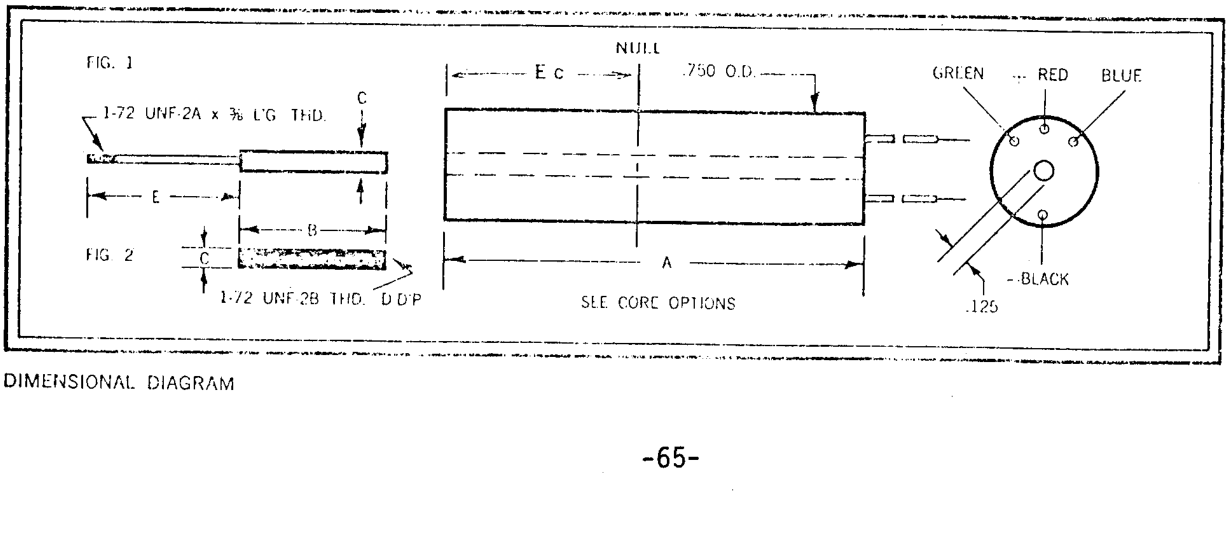
CIRCUIT DIAGRAM



DISPLACEMENT VS. OUTPUT DIAGRAM

CORE OPTIONS

Model	Option	Fig.	Core Pt. No.	B	C	D	E
240-000	Std.	1	C04-000	.562	.120	—	1.90
240-000	1	1	C04-001	.562	.099	—	1.90
240-000	2	2	C05-002	.562	.120	thru	—
240-000	3	2	C05-003	.562	.099	thru	—
241-000	Std.	1	C04-004	.750	.120	—	1.90
241-000	1	1	C04-005	.750	.099	—	1.90
241-000	2	2	C05-009	.750	.120	3/16	—
241-000	3	2	C05-010	.750	.099	3/16	—
242-000	Std.	1	C04-010	1.75	.120	—	1.90
242-000	1	1	C04-006	1.75	.099	—	1.90
243-000	Std.	1	C04-011	1.87	.120	—	2.40
243-000	1	1	C04-007	1.87	.099	—	2.40
244-000	Std.	1	C04-012	2.00	.120	—	3.20
244-000	1	1	C04-008	2.00	.099	—	3.20
245-000	Std.	1	C04-013	3.50	.120	—	5.20
245-000	1	1	C04-009	3.50	.099	—	5.20
246-000	Std.	1	C04-014	3.50	.120	—	8.40
246-000	1	1	C04-015	3.50	.099	—	8.40



DIMENSIONAL DIAGRAM

ELECTRICAL SPECIFICATIONS

Model Number	240-000	241-000	242-000	243-000	244-000	245-000	246-000
Range, working	±0.050	±.100	±.250	±.500	±1.00	±2.00	±3.00
Max. usable	±0.075	±.150	±.375	±.750	±1.50	±2.75	±4.00
Input, volts DC	3.0 Min. to 30 Max.						
Output, full scale DC ± (nom.) open circuit @ 3 V. input	0.55	1.0	0.8	1.4	2.0	2.0	1.5
@ 6 V. input	1.2	2.1	1.6	3.0	4.3	4.0	3.1
@ 15 V. input	3.0	5.4	4.2	7.5	10.8	10.0	7.8
@ 24 V. input	5.0	9.0	7.0	12.5	18.0	16.0	13.0
@ 30 V. input	5.9	10.7	8.3	14.8	21.4	20.0	15.4
Input current	2.8 ma @ 3 V. input to 52 ma @ 30 V. input						
*LINEARITY % FULL SCALE OVER TOTAL WORKING RANGE	±0.5	±0.5	±0.5	±0.5	±0.5	±0.5	±0.5
OVER MAX. USABLE RANGE	±1.0	±1.0	±1.0	±1.0	±1.0	±1.0	±1.0
Internal carrier Freq. Hz Nom. greater than	13000	12000	3600	3400	3200	1500	1400
% Ripple (RMS) nom.	0.7	0.7	0.8	0.8	0.8	1.0	1.0
Output impedance (ohms)	2500	3500	5200	5500	5600	5500	[illegible]
Freq. Response 3 db down Hz	300	140	115	110	100	110	75
Temperature Range	−65° F. to +250° F.						
Resolution	Infinite						

PHYSICAL SPECIFICATIONS

Model Number	240-000	241-000	242-000	243-000	244-000	245-000	246-000
Coil assembly (length A)	0.87	1.12	3.21	3.71	4.71	8.21	10.52
Coil assembly (weight, grams)	22	28	70	80	104	180	220
Core assembly (weight, grams)	1.6	2.1	3.4	3.8	4.3	7.0	8.1
Termination all models	#22 AWG by 18″ long Teflon insulated leads						
E c	0.34	0.46	1.44	1.69	2.19	3.94	5.09

REPLACEMENT CORES

Model Number	240-000	241-000	242-000	243-000	244-000	245-000	246-000
Replacement core Part Numbers	C04-000 C04-001 C05-002 C05-003	C04-004 C04-005 C05-009 C05-010	C04-006 C04-010	C04-007 C04-011	C04-008 C04-012	C04-009 C04-013	C04-014 C04-015

**Linearity is defined as the deviation from the best straight line passing thru zero, is less than 0.5% of the total full scale output over the total working range. ex. (Model 246-000 total working range is 6.00 inches) or 1% of the total usable range.*

MODIFICATIONS

Transducers for special applications are available. Consult Trans-Tek, Inc. on your particular requirements.

ORDER PLACEMENT

United States: orders should be made out to TRANS-TEK, Inc., sent in care of your local TRANS-TEK representative, or directly to TRANS-TEK, Route 83, Ellington, Ct. 06029. **International:** contact your local TRANS-TEK representative.

WARRANTY

All Trans-Tek transducers are warranted against defective materials and workmanship for one year.

NOTES

All specifications and prices subject to change without notice. Contact Trans-Tek for quantity discount prices available on all models and on combined orders. (For areas beyond the United States . . . contact the international representative.)

TRANS-TEK'S PRODUCTS ARE MARKETED NATIONALLY AND INTERNATIONALLY THROUGH OUR SALES REPRESENTATIVE SYSTEM.

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