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BOTTOM ARRAY SPECIFICATIONS FOR THE

LOW FREQUENCY ACOUSTIC SEISMIC EXPERIMENT (LFASE)

by

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1. INTRODUCTION

The Low Frequency Acoustic Seismic Experiment (LFASE) was conducted to measure sound propagation and ambient noise above, at and below the sea floor. To this end an array consisting of four geophone nodes was introduced into a DSDP borehole. These seismic sensors were clamped inside the borehole at various depths below the ocean floor. The geophone array was connected by an electromechanical cable to a bottom reentry structure (BCU frame) housing the Data Recording Unit (DRU), the Data Telemetry Unit (DTU), the Bottom Control Unit (BCU) and the power supply. The borehole reentry operation was accomplished from a conventional research vessel (R/V Melville) equipped with a dynamic positioning (DP) system.

This report describes the borehole array components built at the Woods Hole Oceanographic Institution (WHOI) for the LFASE project. Emphasis is placed on the design and characteristics of the mechanical and electromechanical components of the deep sea borehole reentry system. More detail about the electronic components of the LFASE project can be found in references 1 and 2.

WHOI involvement in this multi-institutional program included the following tasks:

- A) Acquisition and modification of a string of clamped three component borehole seismometers with a passband of 2-50 Hz.

- B) Design and fabrication of a seafloor recording package to digitally record data from the borehole seismometer array over the duration of a month.
- C) Participation in: system sea trials in fall 1988 (San Diego, R/V MELVILLE); seismometers acceptance tests in summer/fall 1988 (France); land borehole test in winter 1989 (Michigan, MIT test site); dress rehearsal cruise in spring 1989 (Miami, R/V MELVILLE); deployment and recovery cruise in summer 1989 (Miami, R/V MELVILLE).
- D) Synthesis and analysis of pre-existing data sets and data acquired from this experiment.

1.1 Brief Program History

Beginning in January 1988 the Ocean Systems and Moorings Laboratory (OS&ML) provided support for the design and fabrication of the bottom control unit package. The effort included test, evaluation and sea deployment of the bottom unit and its interface with the seismic array, built by Compagnie Generale de Geophysique (CGG-France) and with the delivery/recovery system (deep tow thruster), built by Marine Physics Laboratory-Scripps Institution of Oceanography (MPL-SIO). Technical details regarding thruster and bottom package interface, cable characteristics, electrical and mechanical disconnect, bottom package dimensions and loads, release frequencies, and test cruise plans were discussed in late February at a meeting in San Diego between WHOI and SIO representatives.

The BCU frame, pressure housings and the DRU floating module were completed by May 1988 (Figure 1). At the same time all batteries, acoustic releases, electrical pigtails and connectors were purchased. Electronic pressure housings were tested in the pressure vessel (10,000 psi) and the acoustic releases were tested at sea from the R/V ANNANDALE. During the summer the BCU bottom package, completely assembled, was tested from the WHOI dock for handling, acoustic reception, DRU ejection, explosive bolt firing and cable cutter operation. Finally, the BCU bottom package was completely stripped and shipped to MPL-SIO San Diego, for the first sea trial.

FIGURE 1: Bottom Control Unit (BCU) frame.

In August and September 1988 several acceptance tests (mechanical and electrical) were performed in France on the modified seismic array instruments provided by CGG. Members of the WHOI team attended mechanical training (St. Gaudens, Toulouse) and electrical training (Paris) in order to get accustomed with the CGG tools operation. By late October the instrument array was received at WHOI.

The first cruise (R/V MELVILLE) left from SIO San Diego in early October. The following tests were performed:

- a) handling of bottom basket (frame completely instrumented)
- b) communication with BCU through acoustic releases
- c) release of DRU module
- d) partial release of the tether cable from the basket
- e) test of cabling, connectors, pressure cases, batteries of BCU package under actual deep sea conditions.

The LFASE field test was performed at the MIT-Michigan test site (Traverse City) during the first half of January 1989. The following tasks were performed:

- a) handling and deployment of the CGG multi-lock array in a land borehole
- b) testing of the CGG multi-lock array in a situation similar to the field test emulator performed in Marolles, France
- c) measuring seismic signals for both pressure and velocity (three components)

The first test deployment cruise left Miami May 1, 1989 on board the R/V MELVILLE with a joint MPL-SIO and WHOI team. During the first leg of the cruise (Miami to Woods Hole) DSDP holes #417 and #418 were located and marked with transponders. Subsequently the deep tow thruster connected with a BRG probe (both built and operated by MPL-SIO) was lowered to the ocean bottom in an attempt to log the boreholes. Unfortunately both of them were found plugged by sediments (soft mud). During the second leg of the cruise (Woods Hole to Woods Hole) the BCU was completely assembled and connected to the seismic array (four instruments plus DTU). Lowering and handling tests were conducted at the WHOI dock and then at a deep water location just off the continental shelf. At the deep water site the BCU package and seismic

array were connected to the thruster and lowered close to the bottom. With this arrangement the following tests were performed: ship station keeping, acoustic release and Interocean cable release functions, seismic data recording and telemetry, power supplies, explosive bolts, underwater camera and geophones operation. All tests were successful and preparation for the final deployment began at once.

Since DSDP holes #417 and #418 were found impracticable for reentry purposes a new "wiper cruise" was launched to locate and log a new hole. For this purpose DSDP hole #534A ($28^{\circ}21' N$, $75^{\circ}23' W$) was chosen. On July 9, 1989 this hole was successfully reentered by the bottom reentry guide (BRG) and logged to a depth of 150 m below sea floor (bottom depth = 4900 m). On August 8th, 1989 the R/V MELVILLE left Miami for the final deployment cruise with a joint WHOI/SIO team. Two days later the hole #534A was re-entered by the complete LFASE array consisting of: BRG, four downhole three components geophones, BCU frame (sitting in the re-entry core) complete with BCU, DRU, DTU, batteries, camera, acoustic releases, etc. and 275m of EM-soft tether connected to the deep tow thruster (Figure 2 and 3). Seismic data were recorded for three days on the ship, which was connected to the array on the bottom. Subsequently the soft tether was released and the bottom package left in the reentry cone recording and storing data into the DRU.

(a) SHIP DEPLOYING SEISMIC ARRAY

(b) SEISMIC ARRAY DEPLOYED AND CONNECTED TO SHIP

FIGURE 2: Seismic Array deployment.

FIGURE 3: LFASE recording package in reentry cone.

The recovery cruise left Miami on September 1st, 1989 on the R/V MELVILLE with the same joint WHOI/SIO team . On September 4th the BCU bottom package was hooked up by a specially designed hook hanging from the Deep Tow thruster and brought on board. The bottom package and the geophones were found to be in excellent condition and a consistent amount of data was recorded in the optical discs in the DRU. After recovering the transponders deployed around the hole the R/V MELVILLE steamed back to Miami where she arrived on September 10th, 1989.

2. ELECTROMECHANICAL COMPONENTS

The shape and design of the LFASE bottom recording package were dictated by the following requirements:

- a) easy fit in the bottom reentry cone with the top section extending out of it in order to be hooked up by the thruster during recovery
- b) clearance of the R/V MELVILLE A-frame in order to allow safe handling on deck
- c) space for: BCU, DRU (with escape mechanism), DTU, cable cutter, underwater camera, two acoustic releases, cable release, six batteries and all the wiring connecting the instruments to the geophones and to the thruster

- d) reduced weight and maximum stability (i.e. lower center of gravity)
- e) corrosion protection for extended underwater deployment
- f) shearing strength higher than top satellite shearing pin
- g) protection for instruments and wiring inside the frame from the recovery hook
- h) DRU free to escape from frame at any inclination with respect to the ground.

To satisfy weight, strength and corrosion requirements the frame structure was built of welded aluminum 6061-T6 by Cape Marine (Monument Beach, MA). The main structure consisted of schedule 40 pipe (Figure 4). Several holes were drilled all over the frame to allow quick flooding of the pipes during deployment. Sacrificial anode zincs were placed in several locations and all instruments were insulated from their mounts with neoprene pads and delrin bushings. Fiberglass grating was used as a mounting base for the batteries and the junction box. The total weight of the frame was 600 lbs in air and 490 lbs in water. The maximum diameter was 6 ft and overall height 12 ft. The frame was pull tested at the dock with a load of 10,000 lbs.

FIGURE 4: BCU frame general assembly.

The Digital Telemetry Unit (DTU) is located in middle/lower section of the frame and connects to the first geophone through EM cable. The DTU was designed and built in France by CGG to WHOI specifications. Its main components are: hydrophone pre-amplifiers, variable gain amplifiers, analog to digital converter, telemetry unit and power supply. The housing material is stainless steel AISI 431. Maximum dimensions are: 4 inch OD and 58.25 inch length. The air weight is 120 lbs and the wet weight is 20 lbs. The DTU is mounted through the middle and lower hub of the frame and held in position by split bushings made of PVC.

The six underwater batteries were mounted on the fiberglass grating extending over the lower ring of the frame. Each package consists of a oil compensated lead acid battery contained in a molded polyethylene box. Voltage is of 24 volts for 38 AH. The battery is rated for full ocean depth (6,000 m or 10,000 psi) and operates at low temperature without significant loss of power. Weight is 23 lbs in air and 21 lbs in water. This particular model is manufactured by Deep Sea Power and Light Co. (San Diego, CA). Five batteries were connected through the junction box to the BCU. A sixth battery was directly wired to the underwater camera.

The junction box consists of a pressure housing made of anodized 7075-T6 aluminum tubing (O.D. = 7.5 inch, I.D. = 6 inch, length = 17.5 inch). Weight in air is 25 lbs and in water it is 4 lbs buoyant. Five Subconn bulkhead connectors are mounted on one end cap and connect to the battery pigtails. On the other end cap a D.G. O'Brien connector hooks up to the BCU

through a 3#16 molded cable. Inside the housing five diodes prevent accidental shorts from damaging the BCU.

The Bottom Control Unit (BCU) is made of anodized 7075-T6 aluminum tubing (O.D. = 12 inch, I.D. = 10 inch, length 50 inch). Weight is 360 lbs in air and 132 lbs in water. The BCU contains the following electronics: IBM-PC computer, control electronics; high precision clock; power controls; power supplies and telemetry interface with the EM-cable and the CGG instruments. Three bulkhead connectors are mounted on each end cap (five D.G. O'Brien and one Impulse). This allows communication between the BCU and: batteries, DRU, DTU, acoustic releases and EM-cable (Figure 5).

The Data Recording Unit (DRU) is similar to the BCU but includes an outside molded flotation module which provides enough buoyancy to float the DRU to the surface when released (Figure 6). The flotation consists of six syntactic foam rings (density: 43.4 Pcf) fabricated by Cuming Corp. (South Easton, MA). Total air weight is 751 lbs and wet weight is 130 lbs buoyant. A pressure operated light strobe and a VHF radio beacon are located at the tip of the module to aid surface location and recovery. An acoustic pinger is mounted at the bottom of the module to track its ascent path after release from the frame. The DRU contains three optical disc drives and power supplies. One D.G. O'Brien bulkhead connector hooks up the BCU to the DTU. The cable that connects these two components is cut by the cable cutter whenever a release operation is initiated.

FIGURE 5: BCU frame wiring diagram.

FIGURE 6: Data Recording Unit (DRU) and release mechanism

Since the DRU contains all of the experimental data, its recovery is imperative. If the bottom frame is stuck in the reentry cone or the thruster is unable to recover it, then the DRU is released and floats to the surface. For this purpose it was fabricated as a buoyant module with a release mechanism remotely operated from the ship. The DRU sits on a spring loaded sliding carriage powered by a system of bungee cords and pulleys. The release command received by the two acoustic releases goes through the BCU and from there to the two explosive bolts which hold the DRU in place. Once the bolts are fired the DRU is free to escape. Propelled by its buoyancy and by the bungee cords, it pulls on the cable cutter thus trouncing the 37#18 cable connecting the DRU to the BCU. The syntactic foam buoyancy is sufficient to bring the module back to the surface. Several dock tests showed that the DRU was able to escape even with the frame at 45 degrees from the horizontal plane.

The two acoustic releases, model BACS 8202-Deep Acoustic Transponder Release, are fabricated by EG&G Ocean Products, (Cataumet, MA). Each instrument weighs 100 lbs in air and 70 lbs in water. The two instruments were mounted inside the frame between the upper and middle ring, opposite to each other. Depth rating is of 6,000 m. Operating frequencies are: 9-11 KHz for interrogation and 7 to 15 KHz for reply. The mooring release mechanism on the bottom bulkhead was removed since it was not needed for this application. In its place a D.G. O'Brien 9 pin bulkhead connector was installed thus connecting the two acoustic releases to the BCU and to the

explosive bolts. (Two releases and two explosive bolts were installed for redundancy.) The main purpose of the instrument is to act as a communication link between the ship and the recording package on the ocean floor when the latter has been disconnected from the EM-soft tether. The instrument accomplishes two tasks: 1) triggers the explosive bolts and release the DRU in case the bottom package cannot be recovered; 2) changes the data sampling rate by acting on the BCU interface. The two instruments are mounted inside the frame between the middle and upper ring, opposite to each other.

The cable acoustic release is fabricated by Interocean System Inc. (San Diego, CA) and was purchased by MPL-SIO. The unit is made of painted, anodized aluminum 7075-T6 and weighs 10.5 lbs. in air. It is mounted on the top hub of the frame and connects the EM-soft tether hanging from the thruster to the frame itself. It is acoustically triggered from the ship and it releases the lower end of the tether. This action disconnects the bottom package (in the reentry cone) from the surface controller and begins the autonomous operating mode. The release mechanism is driven by a DC motor located in a pressure-compensated, oil filled chamber. The motor torque unlatches the hook holding the cable and under tension the hook opens and releases the cable. This unit was vigorously tested at WHOI and successfully released under an 8,000 lbs tensile load.

3. BOREHOLE SENSORS SYSTEM (CGG ARRAY)

The Borehole sensor system consists of an array of five different instruments connected by EM cable assemblies and one Downhole Telemetry Unit (DTU) mounted inside the frame (Figure 7). The first instrument beginning from the bottom is the Bottom Reentry Guide (BRG), designed and built by MPL-SIO. This instrument will be described in SIO technical papers. The array configuration deployed in borehole #534A was as follows: DTU, 10m, EM cable, satellite #1 (three component geophones and one hydrophone), 30m EM cable, satellite #2 (three component geophone), 30m EM cable, satellite #3 (one vertical and one horizontal geophone), 30m EM cable, satellite #4 (three component geophone), 10m EM cable, BRG (camera, lights, and logging calipers).

The DTU, the four satellites and the EM cable assemblies (with terminations) were built in France by CGG and modified to meet WHOI specifications. The main physical features for a standard satellite are: overall length = 41.22 inch, maximum diameter without pads = 4.39 inch, air weight without arms = 70.5 lbs. Three different sets of pads were provided to fit different size boreholes: France test site, Michigan-MIT test site and DSDP boreholes. The housing is built of stainless steel AISI 431, Bronze ASTM B1489D and Cupro Nickel 150 Cu Ni 14 Al. The top satellite is of similar construction but slightly bigger to house the hydrophone provided by WHOI. Its length is 62.12 inch, maximum diameter is 4.39 inch and air

weight without arms is 103.5 lbs. The hydrophone is manufactured by Ocean & Atmospheric Science Inc, (Dobbs Ferry, NY).

At both ends of the instruments there is a 34-pin electrical connector which matches the EM termination of the cable assembly. Each satellite is provided with a hydraulically operated arm that is opened when inside the borehole. This clamps the instrument in a fixed position and prevents vibrations and noise that would otherwise affect the geophone recordings. The anchoring arm unit can operate at a maximum pressure of 17,070 psi and temperature of 185°C. The anchoring force is 258 lbs for the short arms and 185 lbs for the long arms.

The EM cable is a double armored galvanized plow steel (GIPS) with 18 twisted pairs of TEFZEL insulated (AWG#26) copper conductors. The cable armor design is torque balanced and spin free to avoid kinking and breaking when slack. The cable OD is 0.61 inch and its ultimate breaking strength is 26,400 lbs. Seventeen pairs of conductors are connected to the termination and one pair is a spare. Cable resistance is 42 Ohms/1,000 ft. The termination assemblies are made of stainless steel, bronze, and cupro/nickel components and each conductor is terminated into a single pin Kemlon underwater connector [3]. A rubber boot is slipped on top of the termination and clamped in position for abrasion protection.

At the lower end, each cable termination is mounted on the satellite with a shearing pin. In case the seismic array is stuck inside the hole the pull of the ship will increase gradually and break the weak links as shown in the following table:

TABLE #1

SATELLITE PIN SHEARING FORCE

Satellite No.	Shearing Force (Lbs)
1	7,000
2	6,000
3	5,000
4	4,000

FIGURE 7: CGG geophone array.

REFERENCES

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