SF System:

Submarine Cable Route Engineering

By R. C. ALLEN, D. H. ORT, and L. M. SCHINDEL

(Manuscript received May 12, 1969)

The objective of route engineering in submarine cable work is to select a path for the proposed cable which is both economical and highly reliable from the standpoint of system integrity. The engineering effort begins with selection of the terminal sites and is carried through to a complete route layout. Echo sounding is the principal technique used for deep water route investigations. In shallow water where extraordinary protection measures such as plowing-in of cable may be required, special survey techniques are used to evaluate a route. These latter techniques include side-scan sonar, subbottom profiling, and the application of a Bell Telephone Laboratories developed survey sled.

I. INTRODUCTION

The need for a submarine cable link develops as a result of anticipated or existing demands for communication services. Several factors enter into a general route plan. Among these are: (*i*) system fit—that is, how the submarine cable system will be integrated into existing and planned networks, (*ii*) economics, in a first-cost sense, where the rule is that the shortest cable distance between two points is the most economical, and (*iii*) system reliability, where communications integrity is a prime factor. Economics also plays a part in system reliability in that repair costs above normal system maintenance costs must be considered.

Route engineering of the system begins almost as soon as the communications demand is anticipated. System fit locates the end points, or terminal stations, of the cable system within somewhat restricted geographical limits. Once the general locations of the end points have been established, it remains to apply the remaining guide lines to the overall system. Although some cable routes may be short (several hundred kilometers), major routes may link points separated by 3000 to 6000 kilometers. In the longer routes a great circle route may be the shortest and most economical, but may contain certain environmental hazards which dictate that a devious path be followed. The problem is to select a route for the proposed cable that is economical and yet such that system integrity is assured. In the North Atlantic Ocean, historically, telephone system integrity has suffered most in the relatively shallow (less than 600 meter) depths in the ocean. Here fishing trawlers have caused extensive damage. Deep water portions of cable routes have been relatively trouble free.

The submarine cable system may, for route engineering applications, be considered composed of several parts: (*i*) the terminal station, (*ii*) the continental margin (0 to 600 meters), and (*iii*) deep water portions.

II. TERMINAL SITE SELECTION

The terminal sites of the submarine cable system should be located as near to the shore as possible because the necessary land connection between the terminal building and the sea is subject to the same hazards as any other land cable (excavation by other workmen, conflict with other structures, and so on). The failure of this relatively short portion of the system would, of course, disable an entire transoceanic system. Deep trenching, conduit encased in concrete, warning signs, and in some cases full ownership of the right-of-way are means used to minimize the possibility of failure.

One of the unique requirements of a modern submarine cable system is for a current-carrying ground (called the ocean ground) to be located adjacent to the terminal station. It is part of the return path for the dc current (136 milliamperes in the case of SF Cable) that is carried on the center conductor of the cable to energize the submerged repeaters. This ocean ground, which may be made up of several buried silicon-iron rods, must be located where a uniformly low resistance of about one ohm maximum can be maintained the year around. The ground must be close enough to the station that the series resistance of the connecting cable is correspondingly low. Adequate separation from other underground metallic structures, including the submarine cable itself, must be provided such that the other structures are not adversely affected by the cable system ground current. If the terminal station is sufficiently close to the sea, a satisfactory ground can usually be obtained in a salt water environment adjacent to the landing beach; otherwise, earth resistivity measurements must be made to find a suitable location of the ground and determine the number of silicon-iron rods required.

The nature of the landing beach and adjacent ocean bottom are factors which influence the ultimate location of the terminal building. The beach itself should be open, unobstructed, and located near access roads such that heavy construction equipment—bulldozers, trucks, and power shovels —can be used during installation of the cable, and later for normal maintenance work.

Ideally, the sea bottom approaching the beach should be firm, gradually sloping, and free of boulders or outcropping rock. The slope of the bottom should be such that the cable ship placing the shore end of the cable is able to anchor and still have adequate distance from the land and adjacent shoal areas for maneuvering.

The bottom near the shore is usually examined by divers. If necessary, certain measures such as underwater blasting, split cast iron sleeves, and concrete bags are used to provide a suitable protected path for the cable. Severe erosion may occur in the surf zone, and often cable is excavated or jetted into the beach to a depth of about six feet.

Inland of the terminal building, the communications system is brought into the existing land network. Where possible the submarine cable system is linked to a hardened (blast resistant) coaxial cable route. Redundancy is often provided by a radio relay system.

III. DEEP WATER ROUTE CONSIDERATIONS

The goal of route engineering for a submarine cable system is to determine the best path for the cable from the combined standpoints of first cost and future maintenance. Certain ocean survey operations are required to define engineering parameters.

In the past 30 years, with the advent of electronic depth sounders and other types of exploratory equipment, a great deal has been learned about the configuration and environment of the ocean bottom. Existing knowledge is by no means complete, however, and in certain instances is even subject to error.

Many nations publish navigational and oceanographic charts and exchange information pertinent to them. Charts originated by the U. S. Navy Oceanographic Office (NOO) and Environmental Science Services Administration (ESSA) are among those of greatest value. Bottom contour (BC) charts are available which are to a scale of about 20 kilometers to an inch. A dense concentration of sounding lines is considered to be anything closer than eight kilometers apart.

A great deal of information on the nature of the sea bottom and the movement of water masses may be obtained from published reports of oceanographic institutions such as Scripps Institute of Oceanography

(California), Lamont Geological Observatory (New York), or Woods Hole Oceanographic Institution (Massachusetts). Their reports may include photographs of the bottom and analyses of the nature and depth of bottom sediments. Frequently, oceanographic specialists in particular fields of interest are consulted or retained for studies of specific problems.

Of great value also are the trouble histories of existing submarine cables, particularly the older (19th century) cables. Correlation of their histories with presently available oceanographic information can lead to predictions of the performance of proposed cables.*

It is beyond the scope of this article to present a detailed discussion of the physiography of the sea bottom. The list of references[1–7] will lead the interested reader to the vast literature on the subject. It is enough to say that, just as on land, the sea bottom is divided into physiographic regions — mountain ranges, plateaus, plains, and valleys. The sections shown in Fig. 1 illustrate some of the factors to be considered in route engineering. The major divisions are *continental margin* (including continental shelf and slope), *ocean basin*, and *mid-ocean ridge*; each presents unique environmental considerations.

The principal tool for investigating a proposed route is the echo sounder. This is a hull-mounted, 12-kHz unit, and when used in conjunction with a precision recorder such as the precision depth recorder (PDR), the sounding system provides a depth record which can be read to ± 2 meters (Fig. 2).

The shortest route between terminal sites is initially considered. This route is altered as necessary on the basis of existing information. Thus, gross trouble spots are eliminated. A ship is chartered and one or more echo sounder lines are then made on and parallel to the initial route. During this survey, an area of particular interest, such as the mid-ocean ridge or continental slope, may be examined in detail by means of a closely spaced grid pattern. A resultant, "best possible" deep water route is selected.

IV. SHALLOW WATER ROUTE CONSIDERATIONS

As stated earlier, in the North Atlantic Ocean deep ocean portions of cable routes have been relatively trouble free. The most hazardous portions of routes for cable lie in depths of a few meters to about 600 meters where fishing trawler activity is greatest. The high incidence of cable break and cable damage in these depths led to the development

* For classical studies of this type the reader is referred to various papers in the literature by B. C. Heezen and M. Ewing on the "1929 Grand Banks Turbidity Current." This current was particularly destructive to several existing telegraph cables. See Refs. 1 through 7.

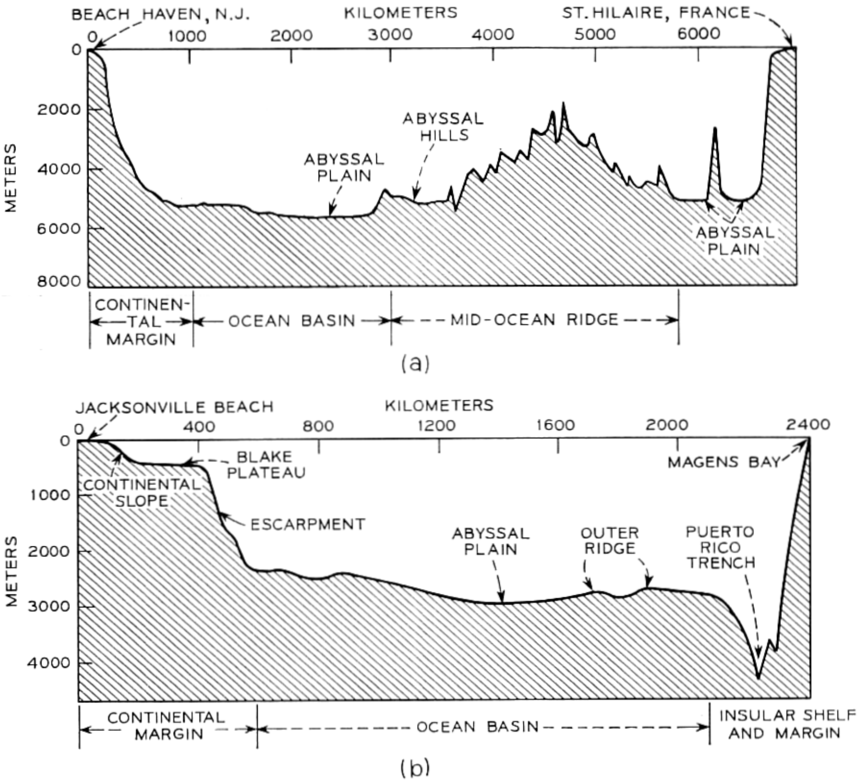

Fig. 1—Profiles of ocean bottom: (a) TAT-4 cable, and (b) Florida-St. Thomas SF Cable.

of the ocean cable plow described by R. E. Mueser and H. A. Baxter.[8] Certain route engineering factors and related survey techniques are associated with use of the plow.

4.1 *Plowing Route Survey*

The survey system used to define a plowing route must provide as much detailed information as possible about the ocean bottom in order to reduce to a minimum the uncertainties associated with the burying operation. In particular, the survey system used must supply information on such matters as:

(*i*) the presence and extent of obstacles such as boulders, rock outcrops, and shipwrecks;

(*ii*) the thickness and extent of sedimentary material;

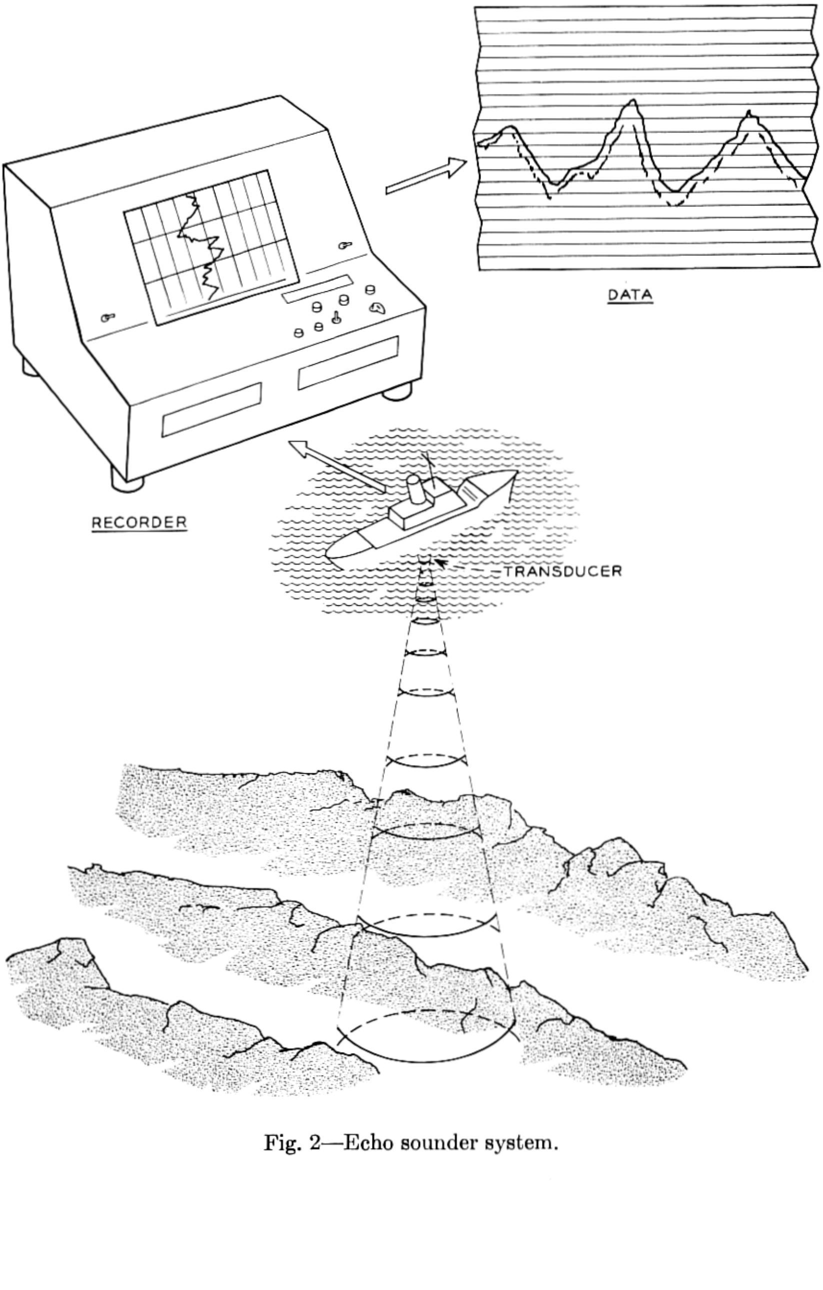

Fig. 2—Echo sounder system.

(*iii*) the engineering properties of bottom materials; and
(*iv*) the overall plowability of the bottom.

The survey technique used to attain these objectives includes three phases:

(*i*) Phase I —reconnaissance survey,
(*ii*) Phase II —sled survey, and
(*iii*) Phase III—trials with ocean cable plow.

The three phases are carried out in a specific time framework. Phases I and II must be completed well in advance of cable installation to permit forwarding of specifications of cable types and lengths to the factory. This lead time is on the order of 12 to 18 months.

Phase I begins with a review of information pertinent to the area of interest and is initiated as soon as the general route plan is formulated. This literature search often is sufficient to describe in broad terms the conditions to be encountered in any area. The scope and type of subsequent work is also determined. The field portion of Phase I typically involves going to sea with a suitable vessel and sufficient equipment to obtain the necessary information for plowing operations.

Phase II, a sled survey, consists of towing a survey sled (equipped with a plow share) along the route selected by Phase I operations. This operation provides a means of evaluating the plowability of the tentative route selected by the reconnaissance survey.

Phase III, towing the ocean cable plow over the selected route to establish a final plowing route, theoretically can be carried out anytime between the completion of the analysis of Phase II data and the actual burying. In practice, it is generally carried out immediately preceding the actual burying operation as part of the burying system sea trials and crew training period.

Proper navigational control is required in each of the survey phases to tie the observed data into spacial coordinates. During Phase I activities, standard Loran or Decca navigation systems are used where available. Positional repeatability to approximately ±1 kilometer ($\pm\frac{1}{2}$ mile) is easily achieved with these systems. For Phase II and III work, a precision navigation system such as Decca HI-FIX with a repeatability of ±50 meters (150 feet) is used. The precision network is referenced as accurately as possible to fixed geodetic positions nearest to the shore station.

4.1.1 *Phase I Reconnaissance Survey*

Because the reconnaissance survey covers a large area, general practice is to lay out proposed survey tracks in a grid network in order to adequately cover the region. The survey equipment used in Phase I includes:

(*i*) Echo sounder (Fig. 2)—This equipment provides a continuous plot of the depth of the ocean along the ship's track.

(*ii*) Seismic profiler (Fig. 3)—The seismic profiler provides information concerning the constituency of the ocean subbottom, (for example, the material from near the water-ocean bottom interface to a few hund-

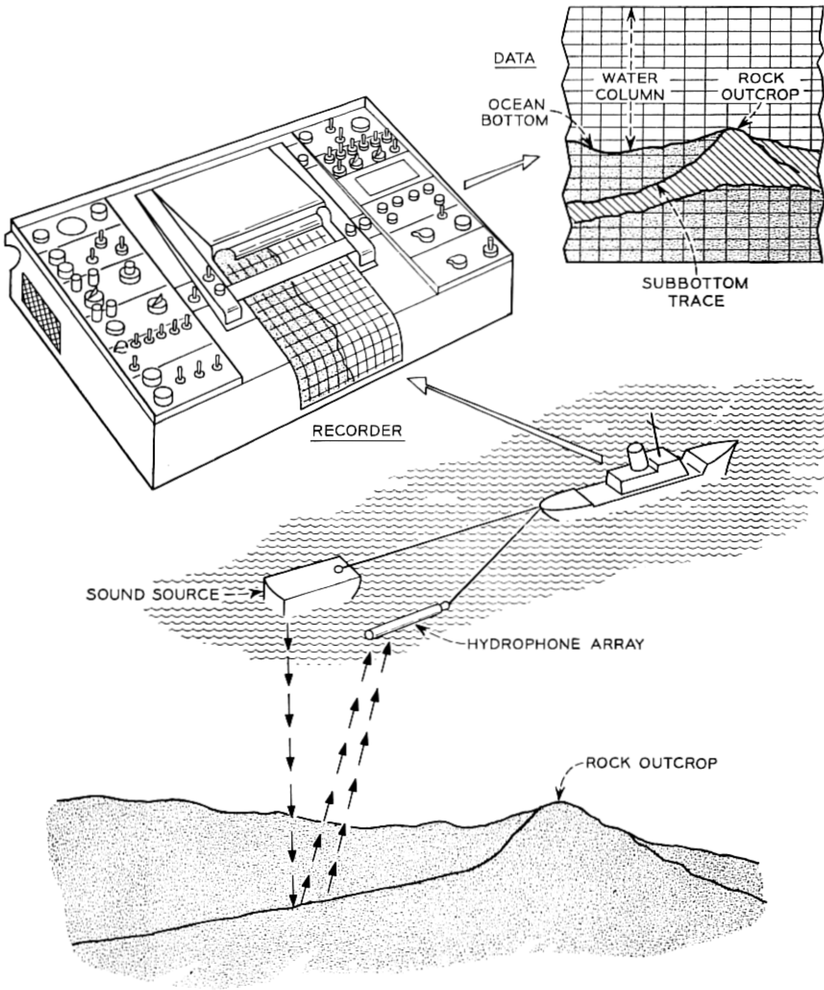

Fig. 3—Seismic profiler system.

red meters beneath the interface). Thus, information concerning rock outcrops and depth to bedrock can be obtained from these data. The equipment consists of a towed sound source, a towed hydrophone array, and a shipboard-mounted recorder.

(*iii*) Side-scanning sonar (Fig. 4)—A side-scanning sonar unit (150 to 250 kHz, depending upon the unit used) provides data concerning materials and objects on the ocean bottom determined from acoustic reflections. The system includes a towed underwater vehicle which contains several banks of acoustic transducers used both as transmitters and receivers. A recorder aboard ship displays the data received by the towed vehicle. This unit provides an effective tool for locating surface rocks, boulders, or shipwrecks which might lie in the survey area.

(*iv*) Bottom sampling (Fig. 5)—This technique consists of dropping a long (on the order of three meters), weighted pipe or a "grab" type sampler into the ocean bottom to obtain samples of the sediment near the surface. The samples can be examined for such characteristics as shear strength, water content, grain size, and so on, and allow a definition of the engineering properties of the materials.

(*v*) Underwater photography (Fig. 6)—A 35-mm camera system consisting of steel frame, camera, flash unit, triggering mechanism, and supporting cable is used to take still pictures of the ocean bottoms at locations selected from the seismic-profiler, echo sounder, and side-scan data.

Upon completion of Phase I field work and a suitable program of data analysis, a composite, three-dimensional description of the area of interest is formulated. The description includes the vertical and horizontal distribution of materials, the engineering properties of these materials, and detailed photographic data for discrete areas within the larger surveyed area. From this information, a route is selected which is optimum for plowing vehicle operations.

4.1.2 *Phase II Sled Survey*

The second phase survey technique consists of towing a Bell Laboratories designed survey sled over the route selected from the Phase I survey data in order to evaluate the plowability of the bottom. The sled (Fig. 7) is about 4 meters long by 2.5 meters wide by 2 meters high and weighs approximately 2700 kilograms in air. A 5-centimeter-thick Bell System "C" plow share is mounted to the aft end of the sled by means of a pivot bolt and a shear pin. The share is provided with two sets of mounting holes which permit the depth of cut of the share to be adjusted

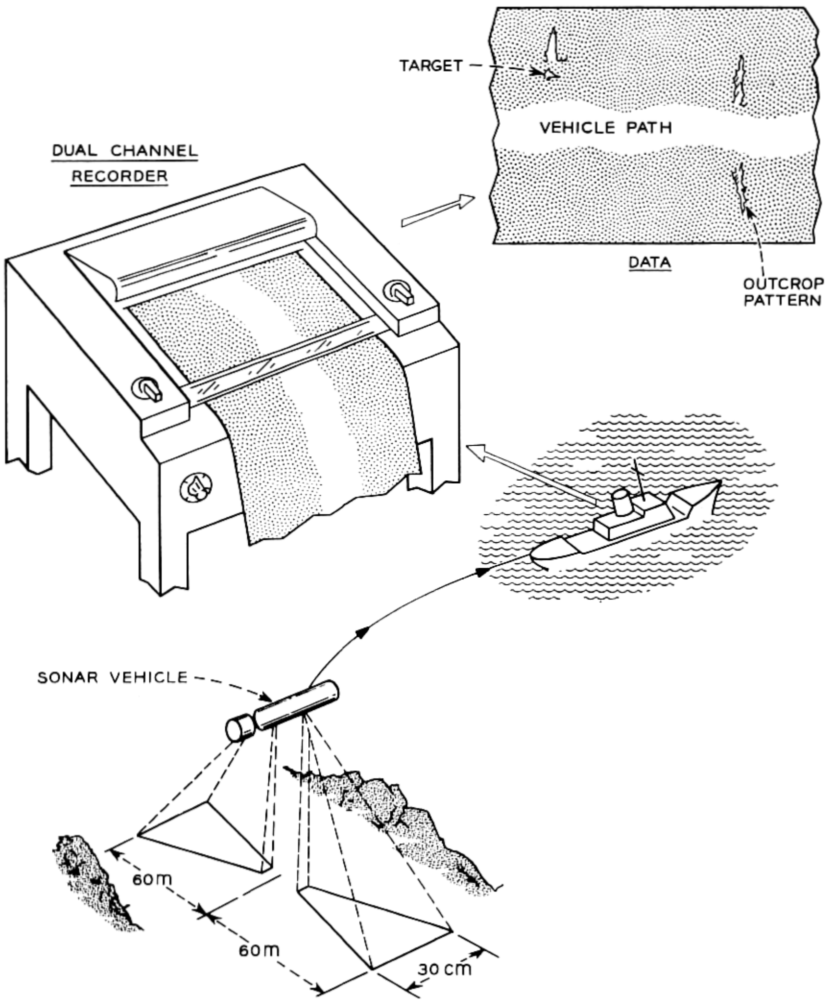

Fig. 4—Side scanning sonar system.

to either 53 or 33 centimeters disturbed depth. The shear pin is included in the design to permit the share to retract should excessively hard bottom be encountered during plowing. If this protective pin does shear, the sled is recovered to replace the broken pin.

An additional safety feature is included in that the towing pad eye on the front of the sled will detach from the sled when towing tensions exceed 20,000 kilograms. This detachment results in transfer of the attached tow chain to the upper (lifting) pad eye, causing the sled to tumble free of the obstacle. Should this happen, the sled is recovered and refitted with slings in preparation for the next launch.

An underwater television camera is provided on the sled to permit visual examination of the ocean bottom over which the sled is towed. The camera is attached to a pan-and-tilt mechanism, thus permitting viewing of the ocean bottom ahead of the sled as well as most of the sled proper. Two mercury vapor lights are used for the television camera, one light mounted forward and one aft near the plow share. A self-contained 70-mm camera and strobe light are also included for taking photographs of the ocean bottom. Shipboard instrumentation includes towing tension and vehicle depth readouts, a television monitor and tape

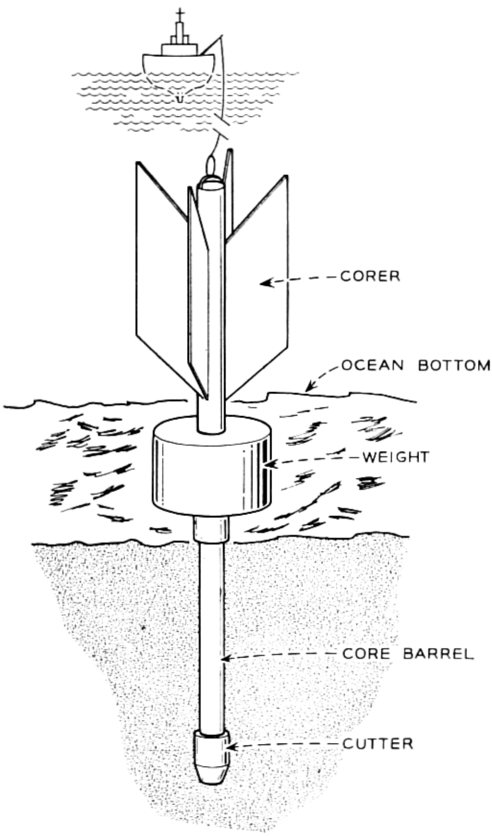

Fig. 5—Bottom sampling.

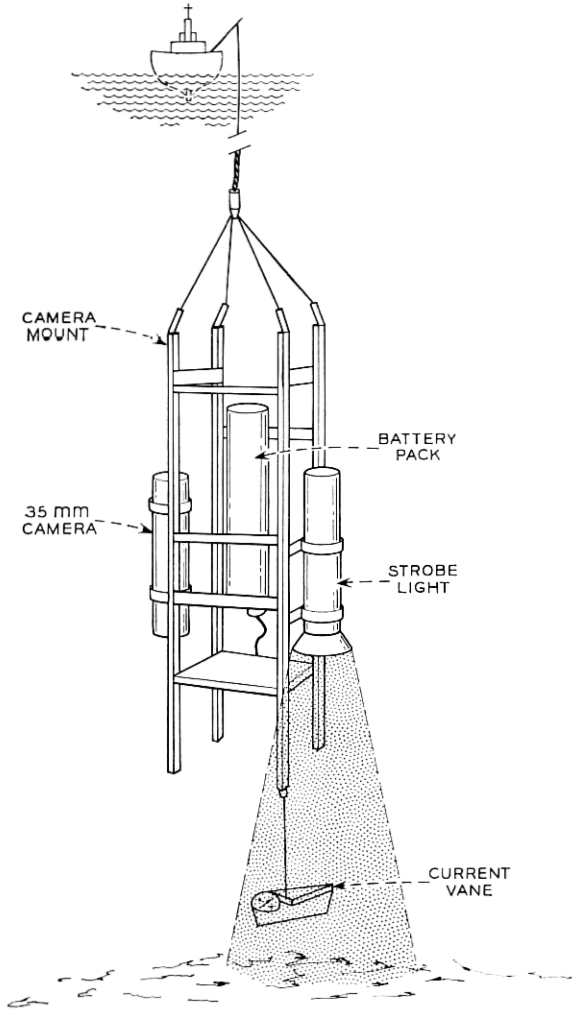

Fig. 6—Camera system (35 mm).

recorder, pan-and-tilt controls, and associated power supplies and supporting electronics.

The sled is connected to the ship by means of a tow wire (2.22 cm diameter and 40,000 kg nominal breaking strength) and a control cable (2.54 cm diameter with 24 pairs of 18-gauge conductors and one 728A coaxial). The tow wire is handled over the bow of the ship; the control cable (which has floats attached to achieve slightly positive buoyancy in water) is handled from the stern. Launching and recovering of the sled are accomplished by using a yard and stay technique.

4.1.3 *Phase III Plow Survey*

For final route verification, the Phase III survey includes the towing of the ocean cable plow along the proposed burying route (as specified by the Phase I and II surveys) without actually burying any cable. This procedure ensures that the route selected has no hidden hazards and that the ocean cable plow is indeed capable of plowing in the selected areas. Also, this period of time (usually immediately prior to the actual cable burying operation) provides a trial period for both the equipment and personnel.

V. FINAL ROUTE LAYOUT

When all of the survey information has been obtained and plotted, it is carefully analyzed, section by section, and the most feasible final route is laid out. It is at this stage that the long, straight courses of

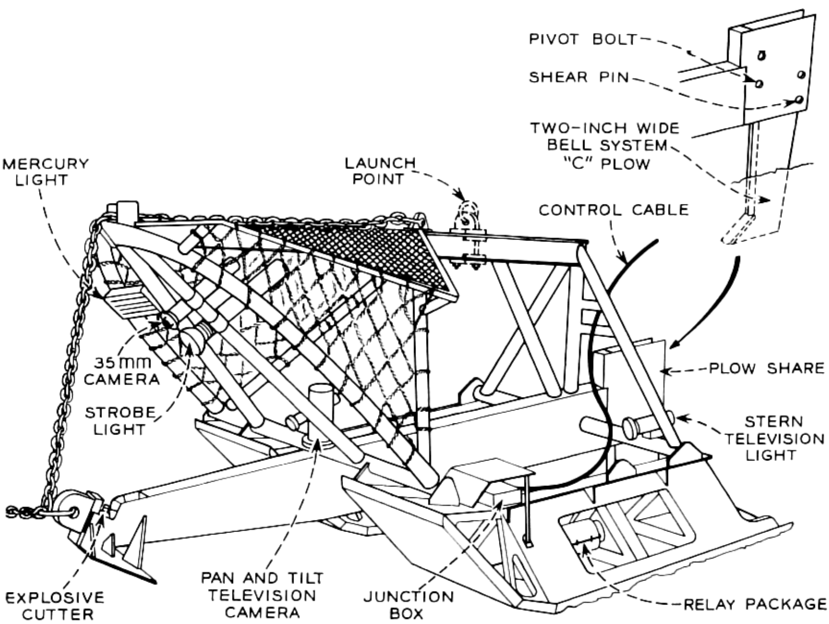

Fig. 7—Ocean bottom survey vehicle.

the preliminary route are broken into a number of shorter ones between angle points known as alter course points. The total route length is determined, first by scaling the distances between alter course points, and, more precisely, by Mercator sailing computations which are usually made independently by more than one person (to insure that the total length of the cable route is accurately determined).

A profile of the ocean bottom along the finally selected route is drawn based on the soundings obtained during the surveys. The profile is usually drawn to a vertical/horizontal scale distortion of 40/1 to make the relief stand out clearly and reduce the total length of the profile chart.

Since slack cannot be laid (nor is it needed) with the ocean cable plow, the length of cable required where plowing is done is virtually the same as the route length. Elsewhere the bottom profile is analyzed to determine: (*i*) the amount of cable slack which must be payed out so that the cable will rest on the bottom; and (*ii*) the maximum speed of the cable ship, section by section, when the cable is laid. Both of these quantities are functions of the slope of the sea bottom. The ideal final condition is to have the cable lie uniformly on the sea bottom at zero tension, hence, without suspensions. Insufficient slack or too fast laying speed would prevent attaining this condition; excessive slack or too slow speed would be wasteful of cable or would require greater ship time than necessary.

Armorless cable is specified for the sections to be plowed in and for laying in water depths greater than 600 or 800 meters. Double-armored cable is usually called for between the beach and the start of plowing where chafing and surf action may occur. Single-armored cable is used where lighter protection is adequate, such as on land and in the less exposed sections in shallow water. Electromagnetic shielding is provided on all cable on and adjacent to land.

The total length of cable of all types that must be manufactured for the project, exclusive of spare for future maintenance, is the sum of:

(*i*) the total route length between terminals,
(*ii*) the total amount of slack to be laid based on the bottom profile,

and

(*iii*) an amount, based on judgement and experience, to cover contingencies arising from deviations from course and other unpredictable occurrences during the laying of the cable.

The cable route engineering program discussed here leads to a complete cable system plan which includes designation of landing sites, overall route configuration, specification of cable types and lengths and, as required, a program of cable protection including cable burying.

If the program is carried out carefully, it can make a vital contribution to the successful placement of the cable system over a route which is economical in first cost, and may be expected to yield a long, low-maintenance service life.

REFERENCES

1. Elmendorf, C. H., and Heezen, B. C., "Oceanographic Information for Engineering Submarine Cable Systems," B.S.T.J. *36*, No. 5 (September 1957), pp. 1047–1093.
2. Guilcher, A., *Coastal and Submarine Morphology*, Methuen and Company, Ltd., 1964.
3. Heezen, B. C., Tharp, M., and Ewing, M., "The Floors of the Ocean: I The North Atlantic," Geological Soc. of Amer. Special Paper 65, April 11, 1959, pp. 1–107.
4. Hill, N. M., (editor), *The Sea*, Vol. 1–3, London: Interscience, 1962.
5. Shepard, F. P., *Submarine Geology*, (second edition), New York: Harper and Row, 1963.
6. Sverdrup, H. U., Johnson, M. W., and Fleming, R. H., *The Oceans*, (fourth edition), New York: Prentice-Hall, 1952.
7. Turekian, K. K., *Oceans*, Englewood Cliffs, New Jersey: Prentice-Hall, 1968.
8. "Burying Ocean Cable," Bell Laboratories Record, *45*, No. 6 (June 1967), pp. 187–191.