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PROPOSED TEST PROGRAM FOR THE INVESTIGATION OF THE PROPAGATION OF SOUND OVER WATER IN FOG

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Cambridge, Massachusetts

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CAMBRIDGE, MASSACHUSETTS • LOS ANGELES, CALIFORNIA

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PROPOSED TEST PROGRAM FOR THE INVESTIGATION OF THE PROPAGATION OF SOUND OVER WATER IN FOG

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U. S. Coast Guard
Headquarters
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PROPOSED TEST PROGRAM FOR THE INVESTIGATION OF THE PROPAGATION OF SOUND OVER WATER IN FOG

1. PURPOSE

For a better understanding of the propagation of sound in the audio frequency range over water in fog -- and to obtain quantitative transmission loss data -- field measurements are urgently needed. The main objective of these tests is to perform acoustic transmission loss measurements while at the same time obtaining micrometeorological data which describe the state of the atmosphere in a manner relevant to the propagation of sound through it.

For the purpose of signalling in fog, the U. S. Coast Guard is primarily interested in the frequency range of from about 100 cps to 1000 cps. If possible, and if time permits, this upper limit will be extended during the measurement program as a matter of scientific interest. It is hoped that enough basic information can be collected to enable Bolt Beranek and Newman Inc. (BBN) to prepare a set of improved design charts for the design of foghorn installations by the Coast Guard.

These charts will be used for the determination of the expected range, optimum frequency (if any), and required acoustic power for foghorn installations taking into account the relevant local conditions. At present the design of such installations is determined, among other things, by average acoustic transmission loss curves, obtained under many different atmospheric conditions many years ago. This procedure has frequently led to unsatisfactory installations.

2. FOG FORMATION

An evaluation of the meteorological conditions along the Eastern seaboard of the United States which are conducive to the formation of fog over the ocean has led to the following:

In order to carry out the proposed measurements, it is necessary that the fog under investigation be relatively dense, uniform and at least of several hours duration (say, 4 hours or more). Of the many types of fog recognized in meteorology, advection fog is the most important type which occurs over water. This type of fog formation usually occurs in the presence of warm moist air of tropical origin

above a cooler water surface. This tropical air is usually carried by winds with a southerly component but fog formation during easterly flow is also encountered. There are indications that formation of a stable layer of dense fog requires over-water trajectories of the warm air of the order of 24 hours. At a mean windspeed of, say, 10 mph, this requires an unobstructed path of open water of at least 250 miles to the south, southeast and southwest of the proposed test site. This is necessary because it is known that even very short land trajectories may alter the wind, temperature, and humidity profiles of the tropical air quite drastically.

3. SITE

The mean number of days of dense fog per year along the North Atlantic seaboard varies: There are about 80 such days at Nantucket, about 70 at Martha's Vineyard, South Shore of Cape Cod 50 to 60, Portland, Maine 15, and Bar Harbor, Maine area 40 to 50 days per year. The fog occurrence tends to increase further out along the Maine coast. With the exception of the Portland area, the above-mentioned areas are situated favorably relative to obtaining the necessary long over-water trajectories. The areas in Massachusetts are,

however, characterized by shallow water near the coast, which hampers the boat operations necessary during the test program. There is also a fairly high density of coastwise traffic which would interfere with the acoustic measurements by creating too much background noise. Both these objectionable features are absent in Maine.

After a thorough consideration of all these factors with Coast Guard personnel and also considering the length of the supply lines for maintaining a crew in the field and other problems of logistics, the site problem was decided in favor of one of the outlying islands in the Bar Harbor area. Of the islands containing a Coast Guard installation, Matinicus, Mt. Desert Rock and Great Duck Island were closely investigated. The last-mentioned island was chosen because of its good landing facilities, comparatively gently rising coastline and its proximity to the Coast Guard Base at Southwest Harbor. A chart of Great Duck Island showing its lighthouse and the nearest surrounding islands is shown in Fig 1.

4. TEMPERATURE AND WIND PROFILES

Little quantitative information is available relative to the vertical temperature and wind profiles in fog over water in

the first 30 to 50 ft. At least the lower part of these profiles is expected to be affected, among other things, by the sea state. On the other hand, the profiles in air having travelled over a long unobstructed over-water trajectory can be assumed to be quite uniform in a horizontal direction. This is advantageous since it is not necessary to locate the micrometeorological mast used for the measurement of the vertical temperature and wind profiles within the course of microphones used for the acoustic measurements. The tower must be located far enough away from the shore so that a) it is in deep enough water that the state of the sea surface is approximately the same as that along the course of microphones and b) the obstacle effect of the rising shore on the wind profile 's small. On the other hand, the anemometers and thermocouples located on the mast must be connected to shore-based equipment by means of a cable. The length of this cable places a practical upper limit on the maximum distance of the tower from shore. As a compromise, a distance of about 250 feet from M.L.W. is contemplated. This equals about 5 times the maximum island elevation. This places the tower near an existing anchor buoy near the Southwest boat slip. It is proposed that the tower be mounted on a special buoy which is

anchored and with the minimum practicable freeboard. This is important, since any appreciable freeboard would interfere with the indications of the lowest instruments. The design of the special buoy will be carried out by the Coast Guard and coordinated with BBN and Simplex Cable and Wire Co.

It is proposed to use a 30-ft tower, instrumented with six matched Beckman and Whitley high-speed anemometers and at least six shielded thermocouples. The output signals will be transmitted by a control cable to shore to the Southwest boathouse where the necessary electronics will be housed. This equipment is so designed that the windspeed differences and temperature differences between two levels on the tower are continuously sampled and recorded. A 115V-60 cps frequency regulated power supply of 2-1/2 kw minimum is required. Frequency regulation to better than ± 1 cps with constant load is necessary.

In addition to the coaxial lines and wire lines which supply the operating voltages to the wind transmitters, twisted wire lines will transmit the output voltages of the thermocouples to shore. A plastic hose will be used to supply dry nitrogen for the continuous purging of the anemometer bearings. All the above-mentioned conductors and the hose have been incorporated into a submarine cable design by Simplex Cable and Wire Co. This cable is lightly armored and weighs approximately 1-1/4 pound per foot. A spare cable will be on hand to be used in case the first cable fails.

5. METEOROLOGICAL AND OPTICAL PROPERTIES OF FOG

Perhaps the only measure of fog density acceptable for practical use by the Coast Guard is visibility. This is defined as the maximum distance at which a black target of specified dimensions is just visible through the fog to a normal observer. Meteorologically, fog must be described also in terms of different parameters. Droplet size distribution and liquid water content per unit volume are such parameters. There are indications that there is a high correlation between liquid water content and visibility. The relationship between liquid water content and visibility is not unique due to the dependence of visibility on droplet size and distribution. However, there are indications that visibility can be estimated from liquid water content within 10% to 20% accuracy. There is no reason why such measurements cannot be performed with shore-based equipment. It is proposed to use several layers of fine mesh screen to collect the water droplets and it is hoped to obtain a fog microscope for the determination of droplet size. Direct visibility estimates will be obtained during the course of the acoustic measurements (see Section 9) by observing the visibility of the last buoy on the measuring course from the LCC. The distance will be determined by radar. It is also planned to consider other instrumentation, made available by the Coast Guard, for the measurement of visibility.

The laying of the cable will best be accomplished in calm weather at high tide with the assistance of appropriate Coast Guard Vessels.

6. ACOUSTICAL PROPERTIES OF FOG

It is also desirable to obtain estimates of the excess acoustic attenuation due to fog. This quantity is difficult to separate from the excess attenuation of sound in the air itself and the excess attenuation due to sound refraction by wind and temperature gradients, primarily upwind. One way to estimate this quantity would be to make measurements of sound transmission in fog at low wind speeds downwind or crosswind, and repeat these measurements without fog under conditions of similar temperature stratification, say, on an overcast day. It is hoped that some light could be shed on the dependence of excess attenuation due to fog as a function of droplet size, which is essentially unknown at this time.

7. OTHER METEOROLOGICAL PARAMETERS

It is proposed that the wind directions and windspeed at a fixed height be measured continuously by a portable Beckman and Whitley Climate Survey Set mounted near the boathouse. This set consists of an anemometer, similar to those used on the mast and a wind vane. The indications of both instruments are obtained in electrical form and are recorded continuously on pen recorders located in or near the boathouse.

A recording barograph and hygro-thermograph mounted in a standard weather bureau instrument shelter will also be provided. To supplement the indications of the hygro-thermograph, a conventional sling psychrometer is provided. The temperature of the sea will be determined directly from thermometric readings near the shore.

8. SEA STATE

It is proposed to measure the peak-to-trough height of the sea from the LCC by means of a lead line. This will be done during the course of the acoustic measurements.

9. MEASUREMENTS OF SOUND TRANSMISSION OVER WATER

Since a course of stationary microphones in the water is impractical, it is contemplated that a series of buoys be accurately laid by the Coast Guard at specified intervals up to a distance of about two miles. The lighthouse will serve conveniently as the zero reference point. Navigation in fog by means of radar is thereby facilitated. Moreover, this landmark will also aid in the initial establishment of the course and setting out of the buoys. The sound source will be a horn loudspeaker energized by a power amplifier located

in the boathouse at the Southwest boat slip. It is contemplated that bands of random noise, one-third octave wide will be used in the frequency range indicated earlier. The use of bands of random noise will aid in minimizing the gross fluctuations with distance in the received signal caused by the interference patterns between the sound source and its acoustical image in the sea. Provisions will also be made in the electronic equipment to make electronic measurements with selected single frequencies if indicated.

It is desired to measure the mean received sound pressure level and its fluctuations as a function of distance, frequency and weather. After establishment of a suitable measuring course (see Section 10) by means of buoys, it is planned to use the 56-ft LCC boat furnished by the Coast Guard for this project as a moving microphone base. A microphone with windscreen will be placed on one outrigger each over the bow and the stern of the boat at about 5 ft height above water. Another microphone will be placed on a mast, away from the radar antenna, at a height of about 25 ft above water. These two heights are judged by the Coast Guard to be representative of the heights of listeners in a fog in a typical small boat and on a typical small ship. After filtering the signal by means

of an octave band analyzer, it is proposed to make recordings of the signal from two microphones at a time on two single-channel magnetic tape recorders for future analysis and evaluation. It is estimated that the 115V-60 cycle power requirements are 150W minimum. Accurate frequency regulation to ±1 cps is necessary.

Since most of the measurements using the experimental sound sources will be made in fog, the operation of the Great Duck Island Foghorn must be coordinated with the program of measurements. Operation at its normal duty cycle of one blast every 15 or 20 seconds will seriously interfere with the measurements. It is extremely important that some measures be taken to minimize this interference. Foghorn soundings may also be required during clear weather for experimental purposes.

Navigation of the LCC up and down the microphone course in fog will be accomplished by radar. The outermost buoy on each course is chosen to return a substantial radar echo to facilitate navigation.

Since it is essential that man-made background noise be at a minimum during the measurements, it is necessary that the

main engines of the LCC be shut down while on station at a buoy. In addition, all other noise sources on the boat must be controlled as far as practicable during the interval in which acoustic measurements are being taken. It is assumed that the crew will be instructed accordingly. Special two-way radio communication between the ship and the shore station in the boathouse on the island will make possible close coordination so that the recordings can be accomplished in a minimum of time. This equipment will be furnished by BBN.

10. MICROPHONE COURSE

It is proposed to lay out a course of buoys on true bearing 180 with distances measured from the lighthouse, as follows:

SOUTH COURSE

Buoy 1S	700 ft
2S	1000 ft
3S	1500 ft
4S	2100 ft
5S	3000 ft
6S	4000 ft
7S	6000 ft
8S	12000 ft

All distances to be laid out carefully within ± 10% accuracy. This course will be used both for upwind measurements in fog during southerly flow and downwind measurements in easterly flow.

To accomplish downwind measurements for southerly conditions, a second course of buoys would be required laid out in the reverse manner and would require the placement of a sound source aboard a second vessel radiating sound into shore. The difficulties of such a procedure are large and obvious. It is therefore planned to lay out another course of buoys on true bearing 065 with distances measured from the lighthouse as follows:

	EAST COURSE
Buoy 1E	1000 ft
2E	1500 ft
3E	2100 ft
4E	3000 ft
5E	4000 ft
6E	6000 ft
7E	12000 ft

All distances to be laid out carefully within ± 10% accuracy.

Figure 2 shows these two courses laid out to scale.

Measuring positions beyond the 12,000-ft range are to be ascertained by radar positioning. Buoys 8S and 7E are first class cans. The remaining marker buoys should be sturdy enough and equipped with heavy enough weights so that they will not be moved by heavy seas. In the event that the measurement procedure requires that the LCC be made fast to the buoys on the course, in order to maintain its position accurately during measurements at a given station, consideration should be given to buoys of a heavier type. Each buoy should be plainly marked with numerals and letters on two opposite sides.

11. SOUND SOURCES

The diaphone installed on the island will be used occasionally as a source for sound transmission measurements simulating actual operating conditions on Course S, being close enough on course, about 100 ft away from the lighthouse. In addition, a horn loudspeaker will be positioned on the rocks 100 ft from the lighthouse oriented along the Smith Course S. Its height above MLW is approximately 40 ft, or 30 ft above MHW. Another like loudspeaker will be positioned on the rocks 275 ft from the lighthouse oriented toward the East course. Its estimated height above sea level is about the same as that of the South Course loudspeaker. Figure 3 shows the layout of loudspeakers, marker buoys and meteorological tower.

It is contemplated to make a limited number of measurements with both loudspeakers elevated to the gallery of the lighthouse. This would raise the source height by about 35 ft. Suitable block and tackle to be provided by the Coast Guard.

12. MEASUREMENTS OF BACKGROUND NOISE

Since very little data are available on sea noise generated in the air close to shore or far out, it is recommended that a brief series of noise measurements be undertaken for various sea states. A simple sound level meter with octave band analyzer, operated by batteries, will be sufficient for this purpose.

13. TIME OF MEASUREMENTS

Examination of the Station Log at Great Duck Island for the past seven years revealed the data shown in Table I. Only days with fog of duration greater than four hours are tabulated, if it is assumed that this is the minimum time necessary for a successful test run. This time limit also tends to eliminate fog occurrences which are local and transitory. On the other hand, no limit of visibility is stated nor is any differentiation made for day or night.

TABLE I

GREAT DUCK ISLAND, MAINE

DAYS OF OCCURRENCE OF FOG OF GREATER THAN 4 HOURS DURATION

May					
		Wind			
	Total	Calm	SE-S-SW	E-NE	Other
1958	11	1	7	3	--
1957	4	1	1	1	1
1956	9	3	5		1
1955	6	--	5	1	--
1954	7	--	4	3	--
1953	11	--	9	1	1
1952	3	--	3	--	--
Total	51	5	34	9	3

June					
1958	7	1	2	1	3
1957	12	1	9	2	--
1956	11	1	9	--	1
1955	11	--	9	2	--
1954	9	1	6	2	--
1953	8	3	3	2	--
1952	8	--	6	2	--
Total	66	7	44	11	4

TABLE I - (continued)

July					
		Wind			
	Total	Calm	SE-S-SW	E-NE	Other
1958	12	4	3	2	3
1957	13	4	6	1	2
1956	No Log	- - - -	- - - - - -	- - - - - -	- - - -
1955	14	--	14	--	--
1954	No Log	- - - -	- - - - - -	- - - - - -	- - - -
1953	9	1	5	1	2
1952	12	2	10	--	--
Total	60	11	38	4	7

August					
1958	10	--	6	--	4
1957	7	3	2	1	1
1956	No Log	- - - -	- - - - - -	- - - - - -	- - - -
1955	17	2	11	3	1
1954	No Log	- - - -	- - - - - -	- - - - - -	- - - -
1953	10	2	5	3	--
1952	12	--	11	1	--
Total	56	7	35	8	6

It is clear that with the layout discussed in the preceding pages, acoustic measurements can be made successfully for calm conditions and wind directions SW through NE. Results of profile measurements are of maximum accuracy only for SW through SE wind directions. Fortunately, these comprise the majority of conditions. Allowing a 20% reduction for fog occurring during nighttime only (when no measurements are feasible), one arrives at the following expectations of days with favorable fog conditions.

TABLE II

AVERAGE NUMBER OF DAYS WITH FOG OF MORE THAN 4 HOURS DURATION DURING DAY

	May	June	July	August
Favorable for acoustic measurements	5½	7	8½	8
Favorable for profile measurements	4½	6	8	6½
All (night and day)	7	9½	12	11

It is therefore concluded that measurements can be profitably begun around the middle of May with increasing expectancy of favorable conditions as time goes by.

It should also be pointed out that the logs show that the majority of conditions of fog occur with winds of less than 10 miles per hour. However, two instances are recorded with approximately 18 mile per hour winds and heavy fog.

It is contemplated to suspend sound transmission measurements in fog when the average wind speed exceeds 20 mph.

14. BBN PERSONNEL

BBN personnel at the site will comprise 4 engineers.

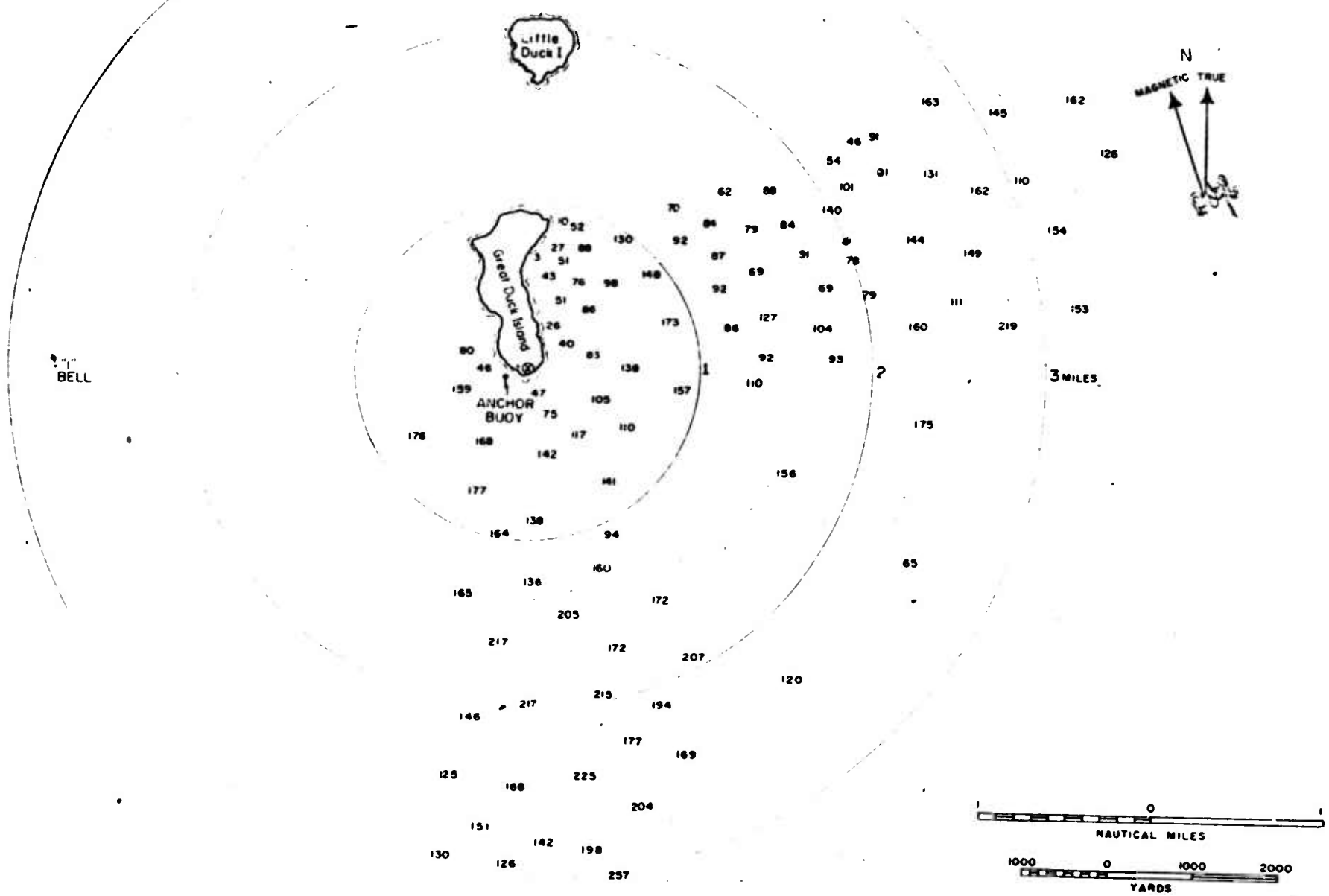


FIG. 1 GREAT DUCK ISLAND, MAINE

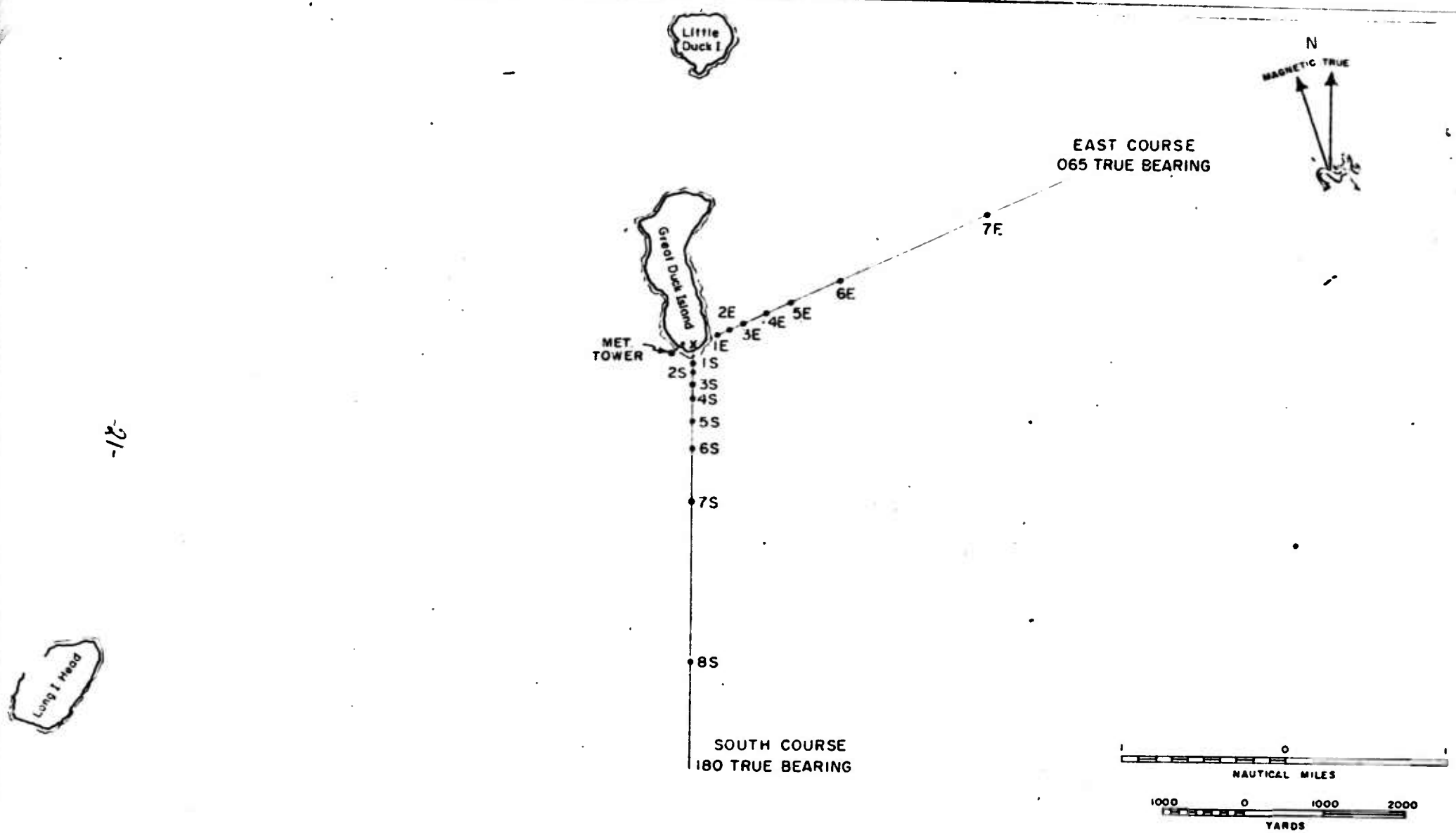
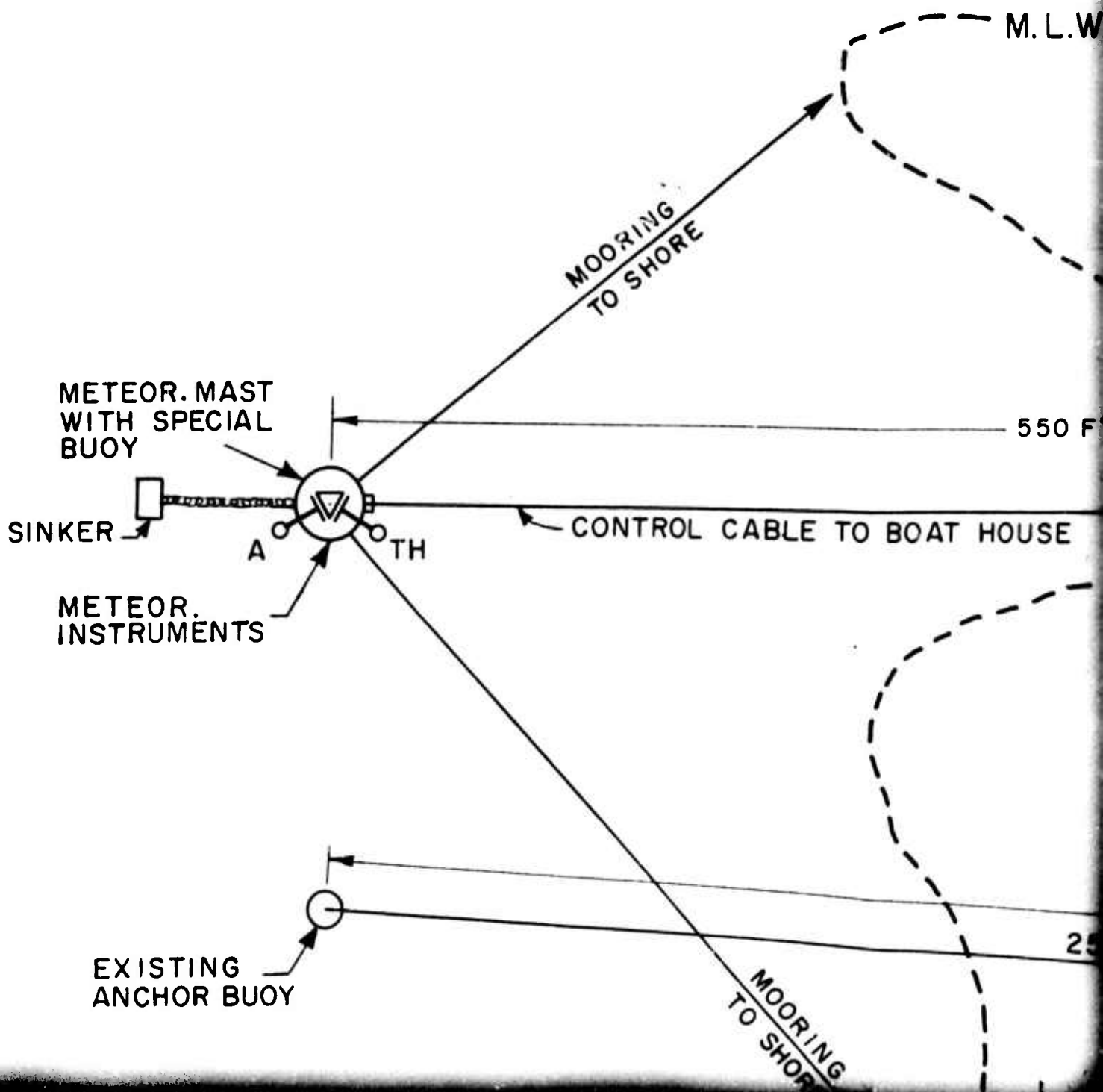
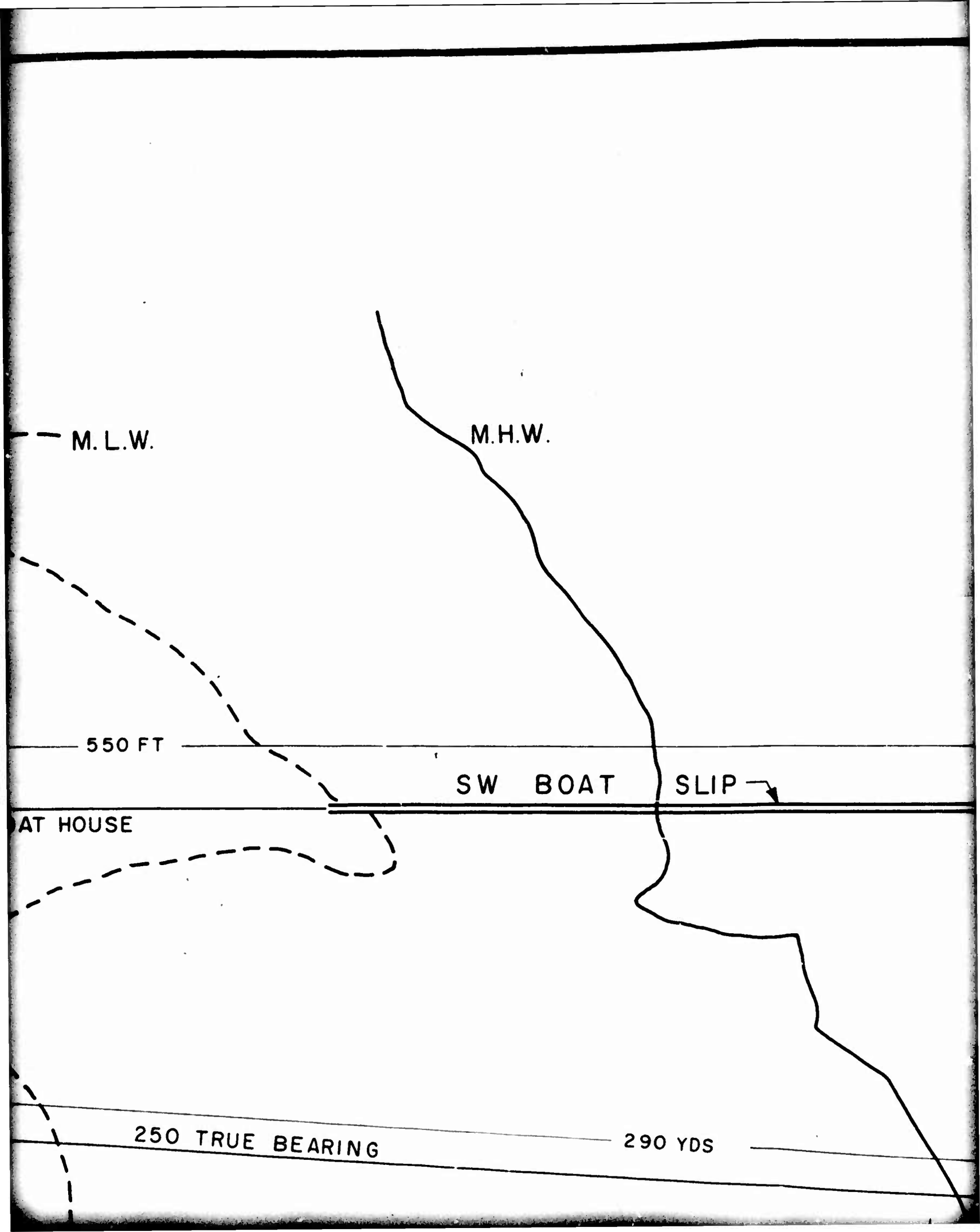
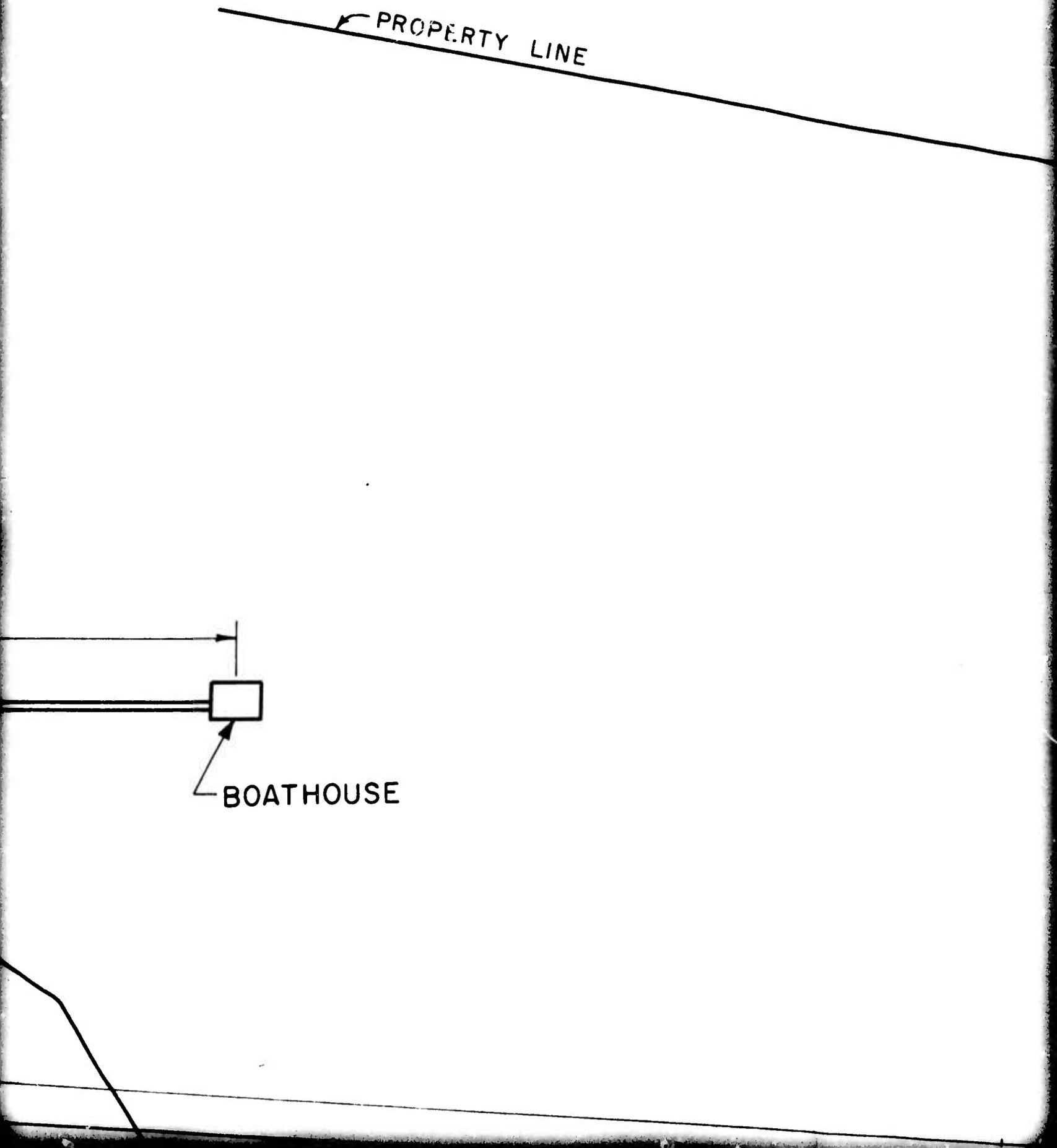
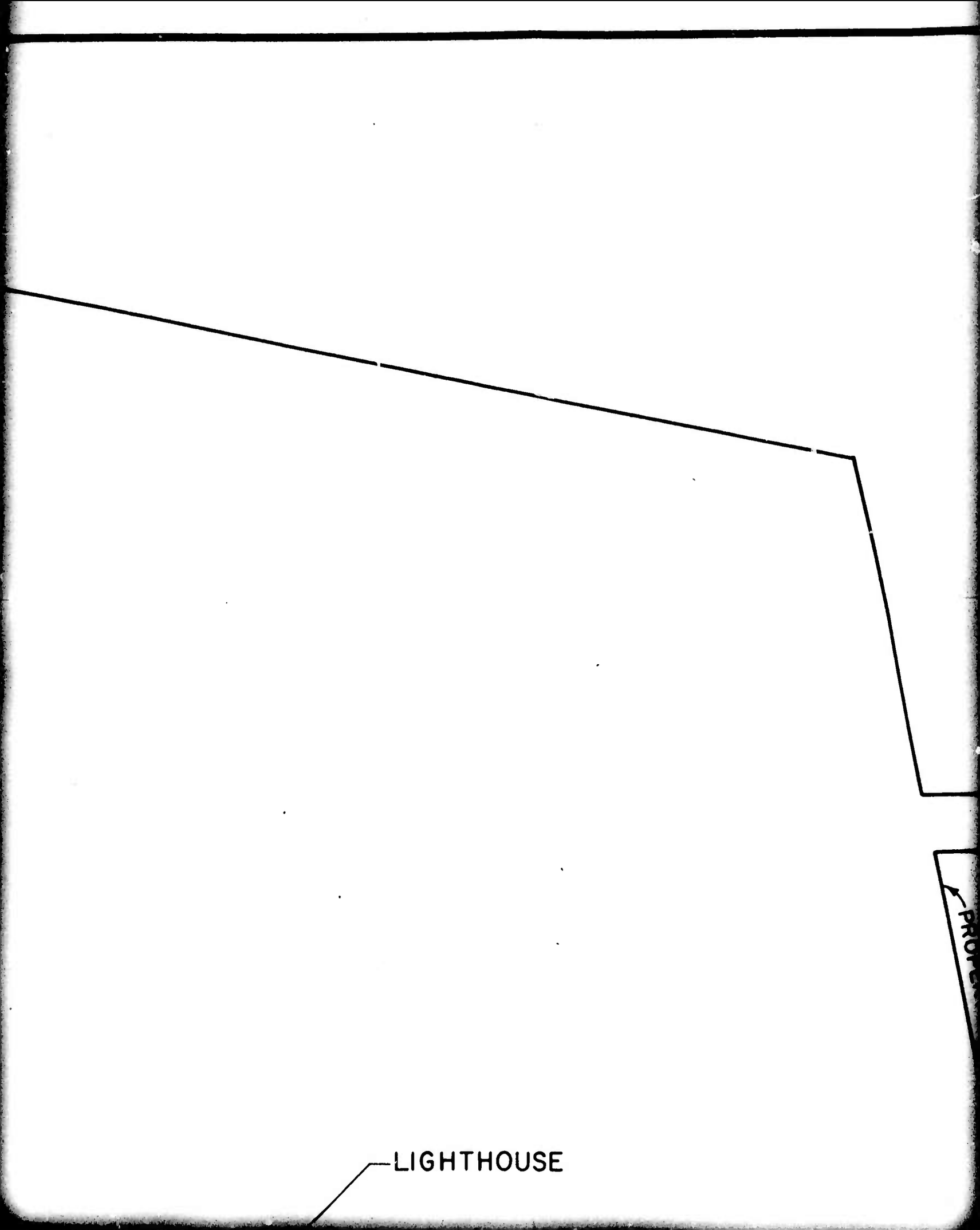


FIG. 2 PROPOSED BUOY COURSES FOR SOUND PROPAGATION MEASUREMENTS


M.L.W
MOORING TO SHORE
METEOR. MAST WITH SPECIAL BUOY
550 F
SINKER
A
TH
CONTROL CABLE TO BOAT HOUSE
METEOR. INSTRUMENTS
EXISTING ANCHOR BUOY
MOORING TO SHOR


M. L.W.
M.H.W.
550 FT
SW BOAT SLIP
AT HOUSE
250 TRUE BEARING
290 YDS


PROPERTY LINE
BOATHOUSE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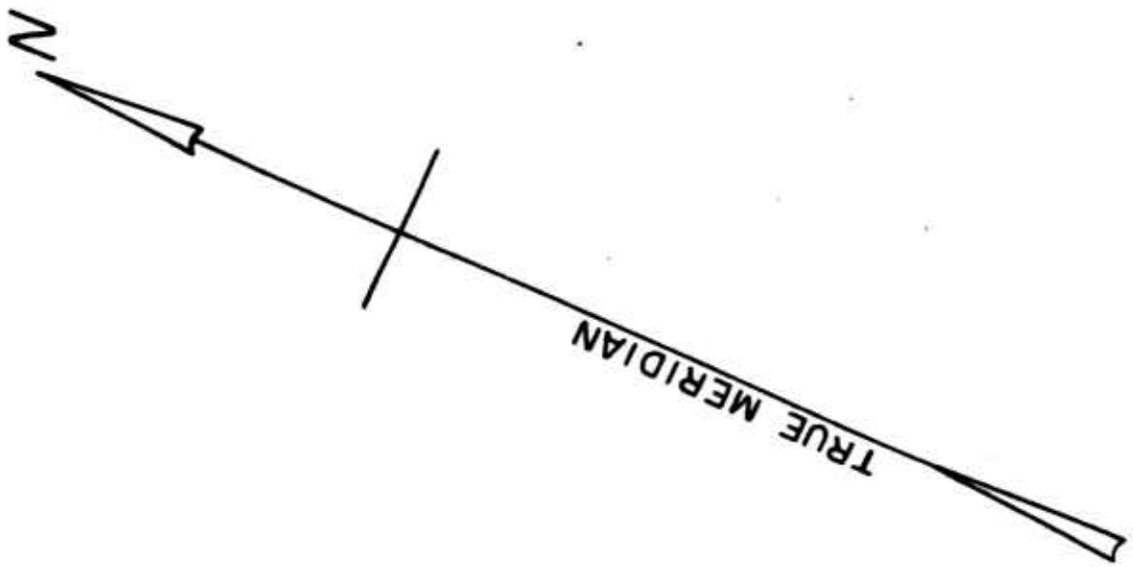
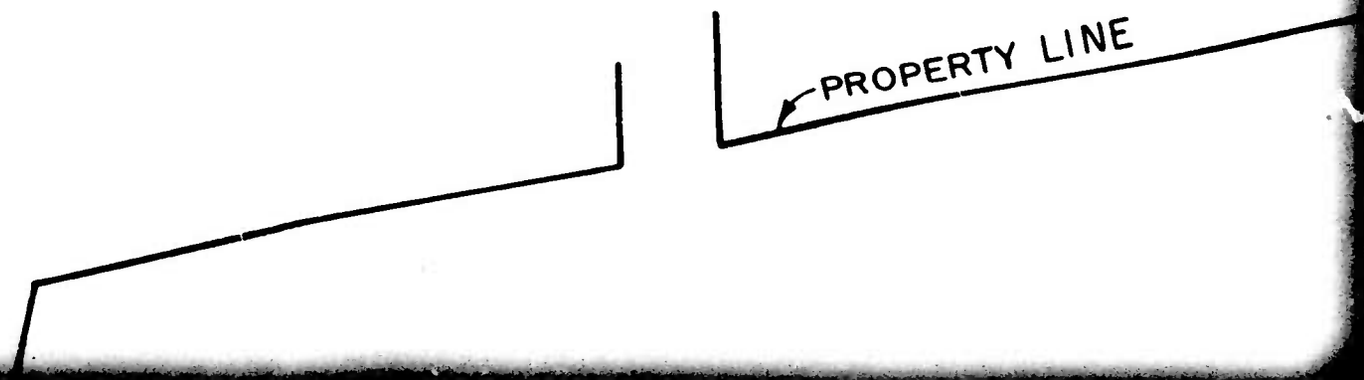
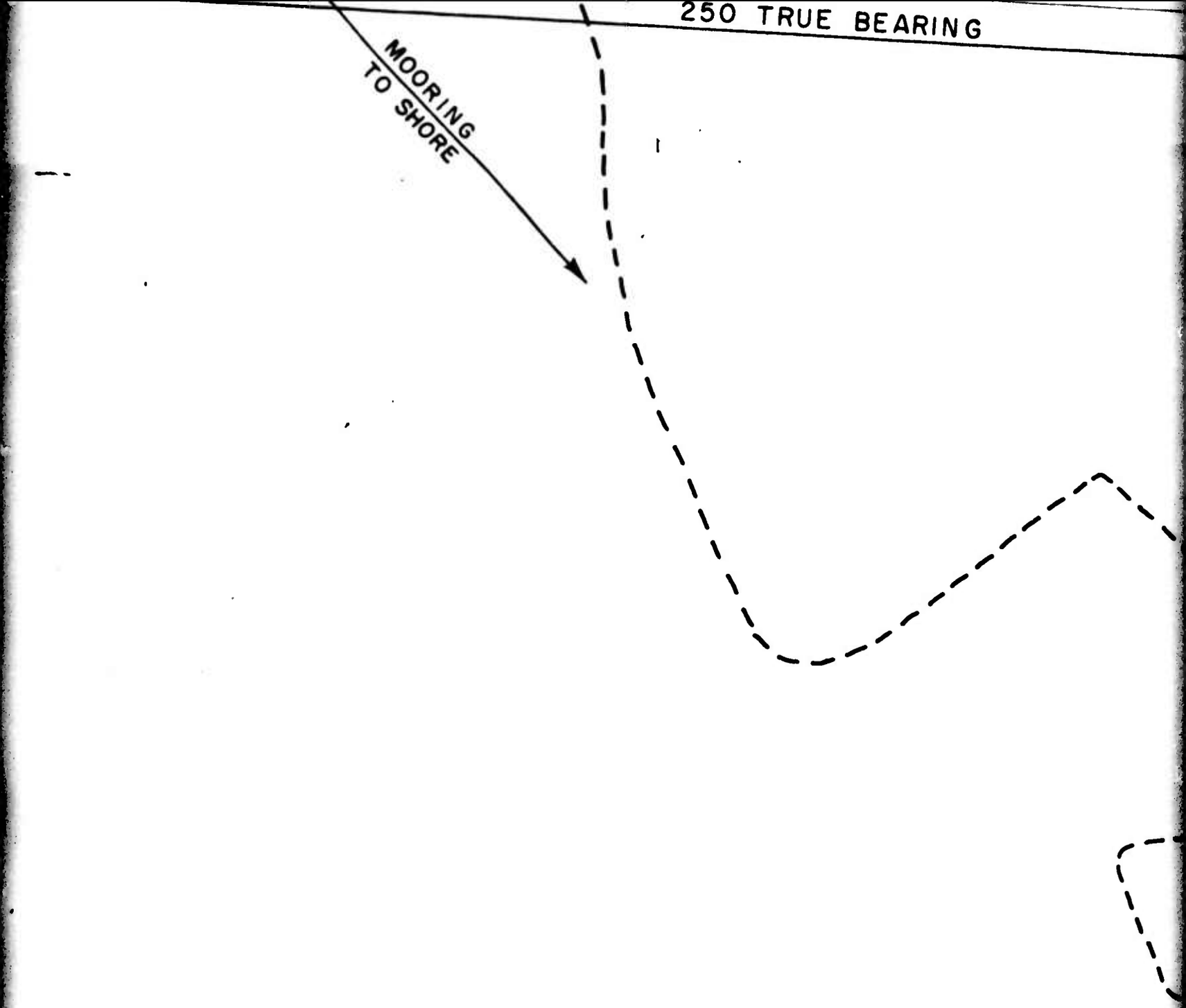

N
TRUE MERIDIAN


PROPERTY LINE


250 TRUE BEARING
MOORING
TO SHORE

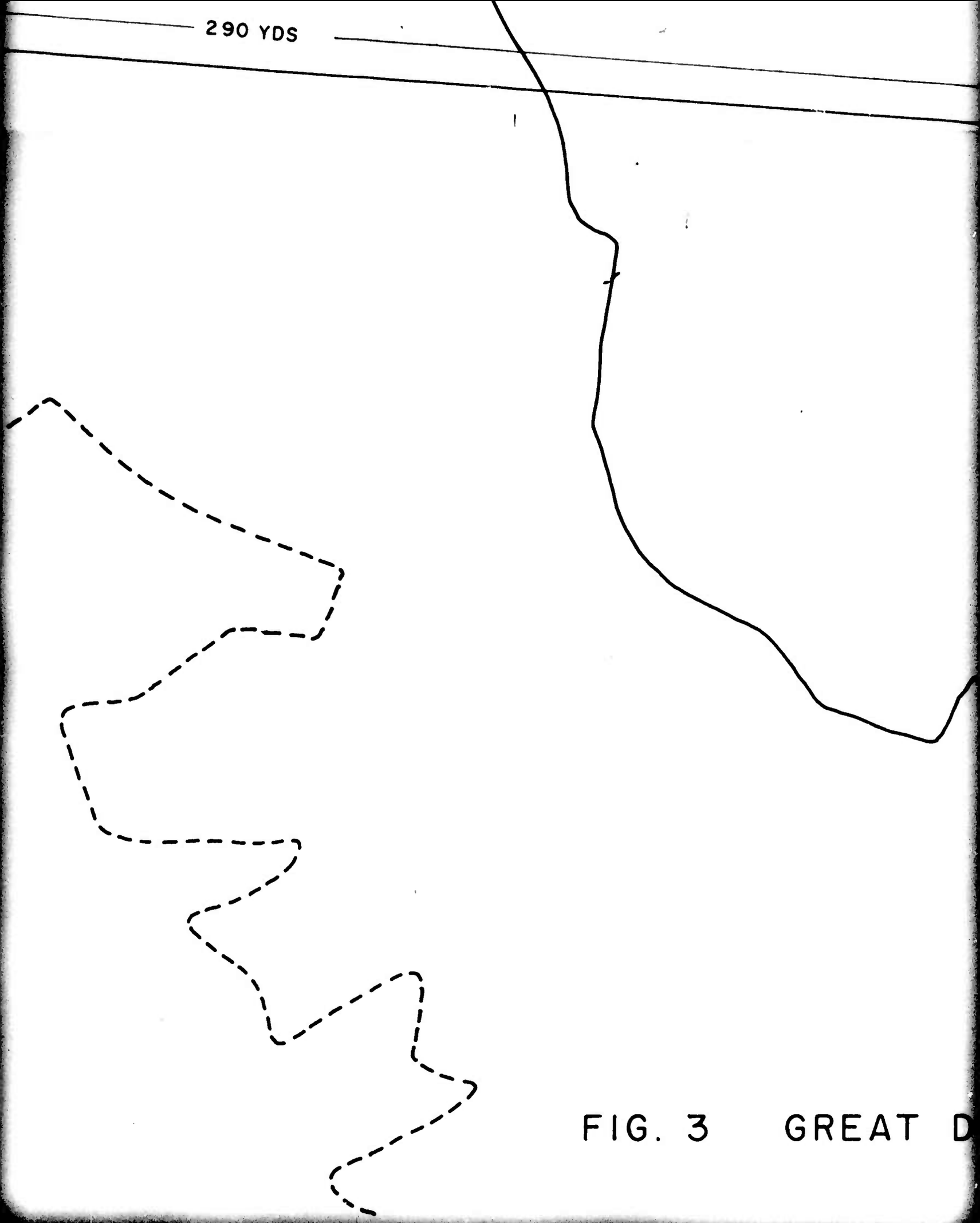
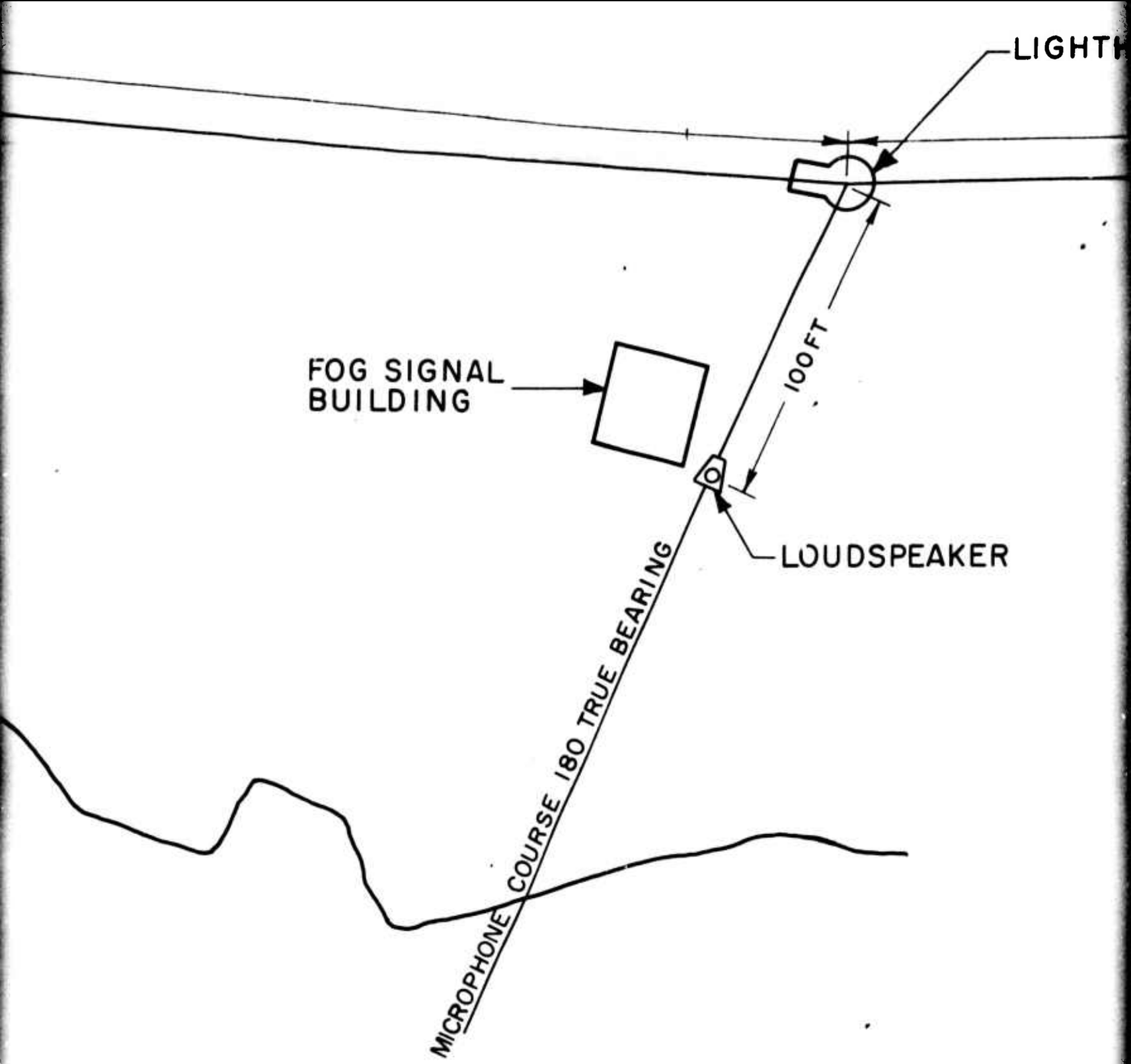
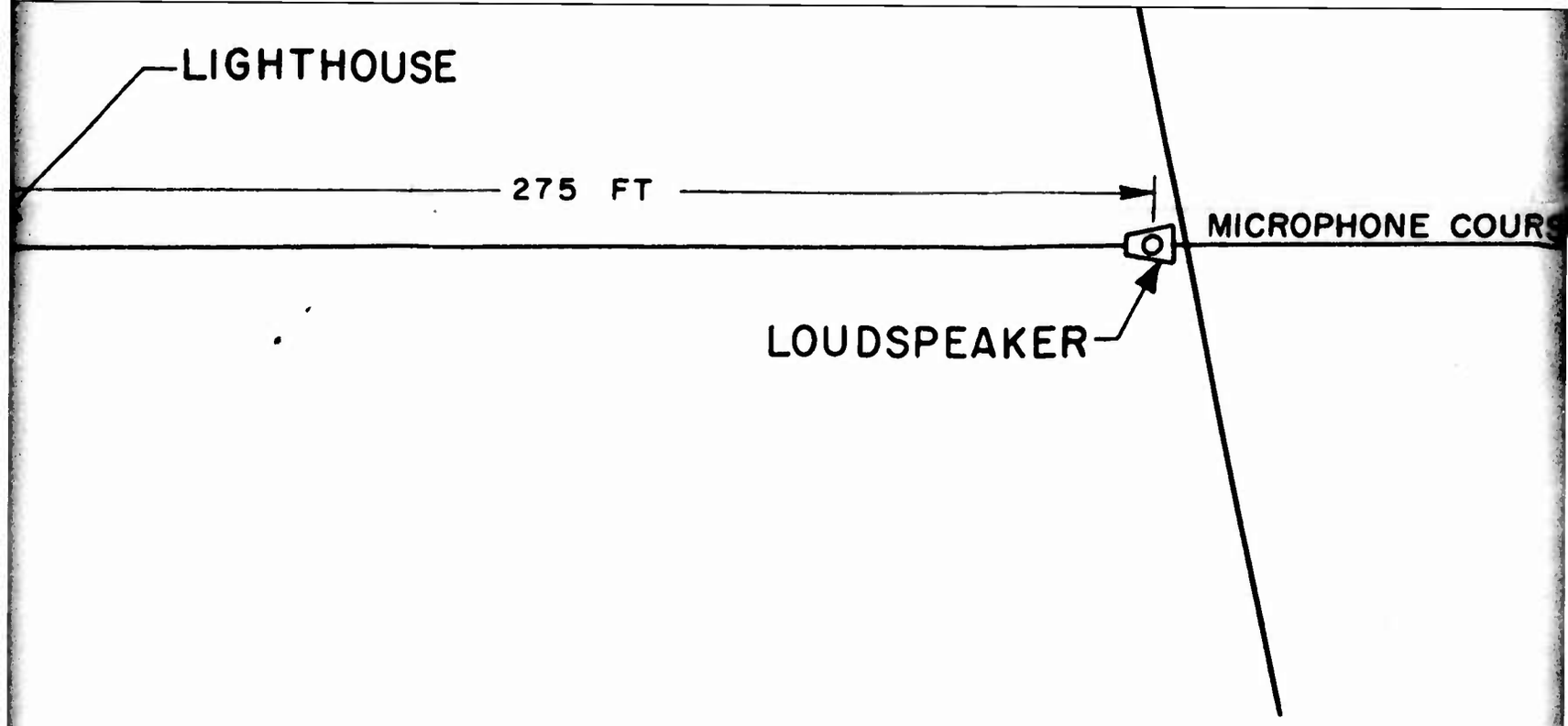


FIG. 3 GREAT D



SCALE 1 IN. =

GREAT DUCK ISLAND, MAINE. INSTRUMENTAT



PEAKER

SCALE 1 IN. = 40 FT

RUMENTATION LAYOUT.