CONSIDERATIONS FOR SITING AND DESIGN OF UNDERWATER TEST RANGES *

William J. Burton

Chesapeake Division
Naval Facilities Engineering Command
Washington, D.C. 20374

ABSTRACT

This paper reviews the major scientific, economic and political considerations that must be addressed in the siting and design of underwater test ranges that are used for the evaluation of mission performance of ships, submarines, and weapons systems. The process of design and placement of such ranges involves compromises principally among the geographic, oceanographic and environmental characteristics of candidate sites while at the same time minimizing the costs associated with the installation and operation of the range(s). This process, with particular emphasis on the impacts of environmental characteristics and shipping densities on site selection and range design, is given special attention.

1. INTRODUCTION

Underwater test ranges may be designed to serve a diversity of needs. Such ranges may have configurations of varying degrees of complexity and may utilize auxiliary equipment and support facilities that are located on shore, on floating platforms, or on towers erected offshore in the proximity of the range(s). The most common applications involve one of three generic types of ranges which will be defined according to their basic purposes and presented shortly. For purposes of this presentation, the ranges will be assumed to be located within a few nautical miles of shore and the necessary auxiliary equipment and facilities necessary to support operation of the ranges will be assumed to be located on shore and as close as practical to the underwater components. The three types of ranges are as follows:

a. Tracking range - This range consists of an array of hydrophones mounted near the sea floor and equipped for tracking of surfaced and submerged vessels, weapons, and targets. Such a range may cover an expanse of several hundred square nautical miles. Typically, the targets, weapons and vessels used in the range exercises are equipped with pingers having coded identifications whose acoustic signals are detected by the hydrophones. The hydrophones, in turn, transmit the signals via cables to signal processing and display equipment based on shore. Through a master timing system and known positions of the hydrophones, the instantaneous position of the target/vessel can be computed based on the temporal measurements of the signal, the acoustic properties of the water, and the spatial geometry of the hydrophone array. Through appropriate coding of the pinger signals, several targets/vessels may be tracked simultaneously.

b. Acoustic range - The so-called acoustic range consists of a single vertical array of hydrophones which in combination with other communication and tracking devices is used primarily for measurement and analysis of hydroacoustic noise radiated by surface vessels and submarines. The data from the acoustic range are transmitted electronically by way of underwater cables to shore-based computer facilities for broad band and narrow band acoustic analysis. The acoustic range requires a test area of about 5x10 nautical miles in order to provide ample maneuvering room for the vessels being tested.

c. Calibration range - This range consists of an array of transponders mounted near the seafloor which along with other ancillary equipment, mounted on board a vessel and on shore, is used for alignment and calibration of the vessel's optical, sonar and radar sensors and other navigational systems. An area of about 5x5 nautical miles is needed to assure ample maneuvering room for the ship or submarine using the range.

As indicated in the brief descriptions of the three ranges given above, there are requirements for shore facilities to support the operations of the underwater ranges. These facilities include buildings and structures to serve a variety of needs. A building is needed to house the range operations center where the data processing and display equipment, the range timing system and the communications center are housed along with the required office space to administer the range workload; there are range support shops for repairing equipment and performing such functions as making ready the mobile targets that are used on the tracking range; there are waterfront buildings and facilities for furnishing operational support for the surface craft used for torpedo and target retrieval and other operational and logistic support functions; and there are air operations buildings and facilities to service helicopters and other aircraft that provide support to the range exercises.

*The opinions or assertions stated herein are those of the author and do not necessarily reflect policies and positions of the Department of the Navy.

U.S. Government work not protected by U.S. copyright.
In conjunction with the tracking range there are shore-based sites situated down range with each site having surveillance equipment for tracking those portions of the range that are located near the surface of the water. The downrange sites are spaced at least one mile apart and each is equipped with radar and other electronic equipment. Each of these sites requires buildings and structures to house and/or support the surveillance and communication equipment.

Electric power to run the essential equipment involved in the operation of the ranges is generated by units independent of a commercial grid. Thus, there are separate generators for the range control center and for the downrange sites and, therefore, buildings to house these installations must be provided.

The process of siting and designing any of the above ranges requires special considerations. First of all, the requirements for the range must be delineated and then a set of criteria established for site selection. The selecting of a site will very likely entail making compromises among the criteria so that the mission of the range can be performed to an acceptable level of satisfaction, yet at a reasonable cost. Following the choosing of a suitable site, the components of the underwater range, the required electronic equipment and shore facilities must be designed or selected.

The following paragraphs present elaborations on the site selection and design processes involved in establishing underwater test ranges. Also some comments on the relative costs with respect to different site situations will be offered. Mention of numerical values with reference to criteria and costs are intentionally avoided in order not to risk the compromising of sensitive information.

2. SITING CRITERIA

The items of criteria used in assessing the candidate sites as locations for an underwater range will, of course, vary with the requirements of the range. For purposes of this discussion, the list of criteria will cover a selection of items whose evaluation would be adequate to cover the general case involving either or all three of the types of ranges previously described.

In order to facilitate the evaluation process, the criteria are grouped into three categories. The categories are then prioritized in decreasing order of importance as: (1) performance, (2) cost, and (3) general convenience. Table 1 presents a breakdown of the items of criteria within each category.

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>CRITERIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>Area dimensions, Operating depth, Oceanographic properties, Environmental aspects, Operational factors</td>
</tr>
<tr>
<td>Cost</td>
<td>Logistics, Shore proximity, Supporting facilities, Personnel</td>
</tr>
<tr>
<td>General Convenience</td>
<td>Shipping, Sovereignty, Fleet transit, Shore topography</td>
</tr>
</tbody>
</table>

Those items in Table 1 that are listed in the performance category are criteria that are essential for a site to meet if the proposed range is to serve its purpose. The site must offer the required dimensions of length, width, depth, and bottom conditions that are needed for installation of the underwater equipment and to provide the required maneuvering room for the vehicles using the range. The properties of the water and its circulation characteristics must be stable so that reliable acoustic data/parameters can be measured and/or computed. Environmental conditions such as sea state, the presence of marine flora and fauna, bottom topography, currents, weather, etc., must be such that the background noise does not obliterate the acoustic signals emanating from the fingers and/or the radiated noise being generated by a vehicle and thereby preclude the pulses being detected by the hydrophones. A favorable environmental setting is also required so that control of and tracking of vessels, weapons and targets while on the range can be accomplished.

Operational factors such as the ability to obtain access to the range at the user's discretion are important. The presence of controlled spaces for air and ship traffic that restrict the passage of vehicles not participating in the range exercises is helpful in this regard.

The second category of criteria shown in Table 1 includes those that have major influences on expanding the costs of installation and operation of the ranges. The cost of supplying logistics support to the range is significantly reduced if an existing Navy base is in close proximity to the site and can accommodate the addition of sufficient facilities and personnel to provide direct support services to the ranges. Furthermore, if the site is situated so that a thriving local economy can provide indirect support to the range through the furnishing of services associated with maintenance, supply, housing, hospitals, etc.,
The closer that the ranges are to the shore, then the shorter the cables can be that stretch from the hydrophones and other underwater communication equipment to the shore-based electronic equipment. Accordingly, steep slopes from the shore down to the depth of water needed for the range are desirable. The reduced lengths of underwater cable as a range is placed closer to shore reduces the cost of equipment and installation of the range. In the case of the tracking and calibration ranges, the proximity to shore provides better surveillance of the range when using the radars and optical tracking equipment.

The item designated "supporting facilities" in Table 1 pertains to the amount of money that will have to be expended to provide adequate shore facilities (e.g., living accommodations for personnel, shop buildings, waterfront facilities, etc.). This is largely a function of the degree of remoteness of the site and, as in the case of "logistics" discussed earlier, the presence of a thriving local economy profoundly reduces the facility requirements and the overall costs of operating a range.

The impact of "personnel" on cost is influenced by the degree of remoteness of the site and thus the salaries and amenities that must be offered to attract and retain qualified people to support the range operations.

Turning now to the third category of criteria listed in Table 1, these items are concerned with those attributes of a candidate site that make it attractive from the standpoint of convenience. Obviously, these items can have impacts on the categories of performance and cost as well.

Shipping traffic that occurs near a range site simultaneously with range operations and is not involved in the range exercise is detrimental in two ways. Firstly, the ship(s) may physically interfere with range operations and, secondly, the noise generated by their presence adds to the background noise of the site and diminishes the quality of the measurements of signals from the vessels and targets reaching the hydrophones.

The siting of a range near territory that is under the control of the United States is preferred to areas that are under foreign domination. The possibilities for siting in/near foreign territory must be evaluated in view of the political stability and attitude of the potential host government and its people, particularly if the operation of the ranges will involve leases of land in the area and support from the local economy. The negotiations of the appropriate treaties and agreements between sovereigns, of course, adds another element of complexity to the siting process.

If vessels must travel inordinate distances to reach a test range, this imposes increased consumption of time, manpower and resources as well as impacting the readiness of the Fleet. Therefore, the required transit distance that will be required is an important criterion in evaluating the overall attractiveness of a site for a test range.

Finally, the shore topography near a candidate site would be assessed for suitable sites for installation and operation of the radar/cineholodite and microwave equipment required for coverage of the range. Accordingly, a shore offering high elevations, providing broad fields of view, that are easily accessible would rank very highly.

The methodology of applying the criteria is to select several candidate sites and then apply the criteria to each site. Each criterion is assigned a weighting factor and the candidate sites are then compared with each other to yield the most promising site.

3. DESIGN CONSIDERATIONS

The underwater components of a test range consist of transducers, cables, seal, support structures, etc., which must be designed/selected and integrated into a workable system. This underwater system must then be made to interface with the shorebased electronics system so that the appropriate data from a test or exercise can be recorded and monitored.

In order to design an adequate underwater range, a variety of types of data apropos of the designated site are needed. An indication of the scope of this background information is given in Table 2. The parameters are grouped into four categories: geology, oceanography, meteorology, and operations analysis. The operations analysis parameters pertain to those human activities that significantly affect the environment of the site.

The installation of equipment for an underwater range requires that structures and mooring and anchoring systems be designed to adequately support and maintain the equipment in its intended position and orientation. Therefore, knowledge of the geological parameters is fundamental to establishing the design of these supports as well as the determination of the best routes to follow in laying the cables from the hydrophones to shore.

The first eight geological parameters are concerned with the basic qualities of the strength of the bottom material, the natural features of the bottom that must be accommodated, and those characteristics of the soil and region that influence the long term integrity of the range installation. These parameters influence the type and size of the major load-bearing surfaces of the structures and determine, when required, the type of anchoring that is most suitable. In those situations where some risk of slumping and other seismic actions must be accommodated, structures and cable routes would be designed and placed so that they would be least vulnerable to damage from earth slides that might occur.
The influence of the seabed on the reflectivity, scattering and absorptivity of sound varies with the type of material and the layering of materials deposited on the bottom. These characteristics affect the acoustics of the basin which, in turn, impact the design and selection of instrumentation and its associated electronic equipment for use on the range.

The first twelve oceanography parameters along with the first four parameters in the operations analysis category are concerned in one way or the other with measurements or computations of key data concerning the environmental noise at the range site. The overall background noise, the sound velocity profile and the noise attenuation characteristics of the water must be known in order to adequately design the range. Knowledge, on a long time basis, of the levels of shipping noise, sea state noise and biological noise over a range of frequencies is needed as are long-term measurements of water properties. This information becomes the basis for determining the specifications for pingers, hydrophones, cables, and signal processing equipment so that the required signal-to-noise ratios are provided to assure reliable detection and tracking of vessels and targets on the range.

The selection of the hydrophones and their geometric configuration are dependent upon the properties of the water, the background noise of the environment, and the source level, frequency and directivity of the acoustic source. In the case of the tracking range, the spacing of the hydrophones is determined by their hearing radii and the degree of redundancy of the hydrophones that is desired for the range. (The hearing radius is the horizontal distance from a source (pinger) to a hydrophone that will detect the signal at a designated signal/noise ratio). For a known source level, the hearing radius may be determined through properly accounting for the attenuation of the signal due to absorption in the water and for curvature of the ray path caused by acoustic refraction. The attenuation coefficient and the acoustic refraction are dependent upon the temperature, salinity and density of the water and on the frequency of the acoustic signal. Having determined the required spacing of the hydrophones, the array is laid out in a manner that will assure its capability to track targets and vessels traversing the required area of the range.

The acoustic range is the most difficult of the three types of ranges to site and match to a design specification. This is because the range must be situated where there are the lowest possible levels of noise generated by the natural environment and where there are the lowest possible levels of man-made noise. Directional arrays can be used to affect a blocking-out of extraneous noise that is directional in nature. Such techniques are used in combination with the skillful positioning of the acoustic range so that it is shielded by natural barriers from the ravages of the open sea and from the noise generated by shipping traffic.

The oceanography parameters numbered 10-14 are

---

**TABLE 2**

<table>
<thead>
<tr>
<th>SITE SURVEY DATA</th>
<th>Parameters</th>
</tr>
</thead>
</table>

The presence of hard sharp edges along proposed cable routes are detrimental to cables and provisions must be made to either avoid them or provide suitable armor, trenching and/or anchoring devices to prevent damage caused by movement of the cables. Similar devices and techniques are also needed to protect cables from being damaged by fishing trawlers.

The influence of the seabed on the reflectivity, scattering and absorptivity of sound varies with the type of material and the layering of materials deposited on the bottom. These characteristics affect the acoustics of the basin which, in turn, impact the design and selection of instrumentation and its associated electronic equipment for use on the range.
Important considerations because of the noise generated when flow occurs past the hydrophones. Also the turbulent action of water flow past structures and cables can be damaging to them and protection from such damage must be designed into the installation. These same concerns for noise generation and protecting of the underwater system apply with respect to the meteorology parameters listed in Table 2.

There are other items such as magnetic and gravitational anomalies, etc., that could conceivably be added to the parameters in Table 2 that would be of importance in special circumstances; however, the list is adequate for most purposes. Another matter of importance to siting and design of test ranges is that of security. Range equipment as well as the details of sensitive tests and exercises must be protected from potential adversaries.

4. COST TRENDS

A few general trends with respect to the costs involved in the design and installation of underwater test ranges can be offered.

1. The lengths of the required cables to reach from the range to shore accounts for the major differences in costs of the underwater systems of similar designs but at different sites.

2. The shore-based electronic systems are basically constant for similar ranges at different sites. The differences depend primarily on differences in requirements for surveillance facilities at the down-range locations.

3. The costs for shore facilities obviously varies greatly depending upon the degree of remoteness of a site. Shore facilities at a remote site can be 3 to 4 times as great as at a similar site located near an existing Navy installation and near a community with a thriving economy. The importing of all personnel and the providing for all services, living accommodations, etc., for them at a remote location also adds significantly to the operating expenses of the range.

5. SUMMARY

Several criteria applicable to site selection have been categorized according to their intrinsic and circumstantial benefits to successful operation of the range(s). Also the importance of some key parameters on the design and installation of test ranges have been presented.

The general requirements and trends pertinent to the design of underwater test ranges are of interest to the technical community and are presented for documentation. In view of the growing emphasis on developing the resources of the ocean, it is important that planners be kept aware of competing interests in ocean space and, likewise, be cognizant of sources of data and information that may be relevant to a variety of projects.