

# WARTIME ADAPTATIONS AND DEVELOPMENTS IN HYDRAULIC ENGINEERING FOR MILITARY AND CIVIL USE

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## INTRODUCTION

In the mobilization of total resources for prosecution of war and hastening of victory, the hydraulic engineer played an important part. All of the acquired experience and knowledge of engineers in various phases of the hydraulic field were utilized in developing equipment and devising plans and techniques for accomplishing the engineering tasks incident to military operations. At the beginning of the war, the existence of hydro-electric developments, waterways improvements, flood protection works, hydraulic equipment and trained personnel facilitated the conversion to war production and continuance of essential civil operations beyond estimable proportions. During the war, continuance of these normal hydraulic engineering functions were of vital importance. In addition, novel applications of new developments in hydraulic and hydrometeorological fields were required to meet special needs peculiar to war. The purpose of this paper is to discuss a few examples in the latter class, and review certain possibilities in the advance of hydraulic and hydrometeorological engineering by applications of war developments during peace.

## HYDRAULIC ENGINEERING IN WARFARE

### *General*

The applications of hydraulic engineering to special problems related to military operations in World War II were far too numerous to recount in a paper of this scope. A few examples only will be mentioned.

The principal element of difference between hydraulic engineering related to military operations and those normally encountered in civil practice arises from the necessity of preparing designs and operational techniques for situations that can not be accurately predicted, and usually, to accomplish this work with very little, if any, actual field data and inspection. The limitations in time, equipment and labor for construction or operation of facilities during active military operations are also governing factors.

When the Allies invaded France in June 1944 it was necessary literally to "take their harbors with them". Most of you have read accounts of the two elaborate artificial harbors that were set up on the Normandy beaches under operation "Mulberry". One of these harbors was wrecked by a violent storm that occurred shortly after the structures were set in operation, but the other functioned in an excellent manner and served a vital role in the unloading of heavy equipment for sustaining the drive through France. One of the important features of the artificial harbors was the design of portable breakwaters, the units consisting of portable concrete caissons that were constructed in England, towed to location and sunk in position to protect the portable docks and floating causeways from wave action. Over a hundred units were constructed.

In the design of the portable breakwater, model tests were made to determine the degree of protection that would be afforded by the line of caissons, and the scour, settling, sliding, and overturning characteristics of the units. The towing characteristics, and need or advantages of sand ballasting after the caissons were in place, were also investigated. A summary of the tests is presented in a paper by Robert T. Hudson, September, 1945 issue of *Civil Engineering*.

Although the engineering techniques involved in studies of the portable caissons differed only in detail from those used in certain types of civil work, they emphasize the important role that hydraulic laboratories and hydraulic techniques may play in the military field. Other examples of a similar nature that may be mentioned are:

a. Model study of locations for a proposed breakwater in San Juan Harbor, Puerto Rico. In this case an extensive system of breakwaters was developed for protection of seaplanes against

heavy wave action. Plans originally proposed were shown to be unsuitable, and an effective arrangement was devised.

b. Model study of wave and surge, Naval Operating Base, Terminal Island, San Pedro, California. This base was one of the most important for support of operations in the Pacific Theater. An effective harbor plan was developed. Contrary to the opinion of most engineers familiar with problems involving wave action, this study showed rather conclusively that sufficient long-period wave energy can pass through a rubble-mound type breakwater to set up standing waves of appreciable amplitude in the harbor area, and that breakwater extensions used to inclose the harbor should be constructed in such manner as to be impervious to long-period waves.

c. Model tests of the Intra-coastal Waterway cutoff, vicinity of Savannah River, Georgia. These were made in developing a safe route for oil shipments during the height of the Germans' submarine campaign.

A somewhat different phase of hydraulic engineering was involved in the analyses of flood characteristics of major rivers in Europe and in the establishment of a flood prediction service to assist in the planning and execution of river crossings, particularly the Rhine crossing. In planning for bridging requirements and amphibious equipment, it was necessary to estimate the width of river channels and flood plains at numerous points suitable for crossings, and to have a reasonable knowledge of current velocities and depths under which bridging and amphibious operations were to be conducted. Knowledge of flood dangers was also important in locating supply dumps, sites for hospitals, camps and other installations where they would be least affected by inundations. Extensive hydraulic analyses were required to supplement and verify the limited hydrologic data available.

The presence of several large reservoirs on rivers to be crossed offered a threat of artificial floods that could be created by enemy demolition of the dams or by manipulation of control gates. The possible magnitude and duration of artificial flooding below these dams was estimated by hydraulic engineers. In certain cases, as in the crossing of the Roer River, floods were actually created by the enemy's demolition of the outlet control works of dams. Delays

and hazards from these floods were greatly reduced by the hydraulic engineer's analyses of the situation and forecasts of the extent and duration of flooding. The jumping-off time for allied crossings of the Roer after the artificial flood had subsided was fixed by the hydraulic engineer's estimate of the flood recession. In other cases, possible artificial floods did not take place, but preparations had been made for the eventuality. A special study of this character will be described later.

### *Rhine River Flood Prediction Service*

The crossing of the Rhine River was classed by military personnel as a "major amphibious operation". Enormous quantities of amphibious equipment, floating craft, pontoon bridging, cable ferries, and temporary fixed bridges were used in the massive crossing operations. An even greater undertaking would have been involved if enemy resistance had been as strong as originally anticipated, and the unforeseen capture of the Remagen bridge had not materialized. It does not require unusual military knowledge or imagination to visualize the disastrous effects that might have been produced by an unexpected major flood on the Rhine River during and immediately after initial crossing operations began. Once an operation of this magnitude is set in motion, it is extremely difficult or disastrous to suspend the action. Accordingly, it was vitally important to military strategists to know from a week to ten days in advance that a major flood on the Rhine would not occur on the day set for the crossings. Once the initial crossing had been effected, it was essential that advance warnings of any significant floods on the Rhine or major tributaries be made known to Army personnel in the field in order that appropriate measures could be taken to protect the floating craft and bridges that were necessary for sustaining their life-line of supplies.

During this most critical period of operations, the major portion of the flood-producing areas of the Rhine basin were under enemy control. Direct observations of Rhine River stages were practicable only at a few points upstream from Strassburg, and on the upper reaches of the Mosell River. Rainfall reports were available only from irregularly spaced mobile weather detachments operating under the Air Corps. Meteorological maps prepared by the Weather

Service of the Air Corps for operation of aircraft were available for analysis. On the basis of these limited data, it was necessary for the hydraulic engineer and hydrometeorologist to estimate the quantity of rainfall that had fallen over various portions of the Rhine basin in the period immediately preceding the forecast, predict the quantity to be anticipated 12 to 24 hours in advance, and estimate hydrographs of flow at key points on the Rhine River from Bale, Switzerland, to Nijmegen near the mouth. Quantitative forecasts of precipitation, and quantitative estimates of precipitation from meteorological maps covering areas not served by observation posts, were important factors in the river stage predictions. An intimate knowledge of river hydraulics was, of course, a basic requisite for engineers responsible for river stage predictions.

River stage predictions are a very perishable commodity. An accurate prediction was of no value unless it could be made available to Army personnel in the field in time for them to take necessary measures for protection of their floating craft and bridges. The mobility of field units, the complete disruption of normal communications channels, and frequent changes in personnel, imposed the greatest of difficulties in maintaining two-way communications. However, by the excellent cooperation of all Army units and organizations, communications were successfully maintained at all critical times.

The Rhine River flood prediction service was continued on a modified scale for several months after the initial crossing operations, to aid in protection of temporary bridges and navigation. The work is now carried on largely by civilian engineers of the countries bordering the Rhine.

The conditions encountered by the Rhine River Flood Prediction Section may never be encountered again. Improvements in forecasting of storm conditions, possibly by aid of radar, and new methods of communications will most likely change prediction procedures even if, unhappily, circumstances occur that necessitate a similar service. It is believed, however, that the hydraulic engineer will play an essential part in any such service irrespective of the advent of new tools.

*Intentional Flooding as a Weapon of Warfare*

On a number of occasions during the war the "hydraulic weapon" was used as a means of defense or for destruction of productive capacity of war industries. When the Germans invaded the Low Lands at the beginning of the war, extensive portions of leveed areas were flooded by the Dutch to interfere with the invader's advance. During the campaign in Italy, crossing of the Garigliana River by the Allies was temporarily delayed by alternating high releases of water from reservoirs controlled by the enemy. A similar delay occurred in the crossing of the Roer River when the outlet controls of the Schwammenauel and Urfttalsperre dams were demolished by the Germans. Several other instances of this nature might be recited. The danger of artificial flooding of low areas from demolition of dams or levees was a major factor to be considered in the planning of military operations in Western Europe.

One of the most spectacular examples of intentional flooding as a destructive force in warfare was the devastating flood caused by bombing of the Mohne Dam in the Ruhr Valley by the British Royal Air Force in May 1943. The primary purpose of this bombing was to deprive the enemy of water supply and hydro-electric power required for the extensive war industries in the Ruhr basin. Quite apart from the military significance of this action, the hydraulic engineer will be interested in the effect and nature of the flood wave created by breaching of the dam. Information available regarding hydraulic details of the flood are very limited, although intelligence documents and photographs by the Allied Forces contain considerable data that should permit reconstruction of the picture sufficiently for certain engineering purposes when fully analyzed.

The Mohne dam was a concrete structure, approximately 105 feet high above river level, that formed a reservoir of 109,000-acre-foot capacity. Approximately 75 per cent of the impounded waters were released in a period of 10 hours by the bombing of the dam. This is equivalent to an average rate of discharge of approximately 100,000 c.f.s., although the peak discharge was of course substantially higher. The discharge of the Rhine River below the mouth of the Ruhr was said to have increased approximately 150,000 c.f.s. as a result of breaching of the dam.

The following information deduced from Allied intelligence summaries gives an indication of flood heights and velocities at various points down-stream from the Mohne dam. All values should be considered approximate.

<i>Location</i>	<i>Distance from Mohne Dam, in miles</i>	<i>Maximum Stage of Flood above Normal in feet</i>	<i>Mean Velocity of Flood Progression, in feet per second</i>	<i>Remarks</i>
Gunne	0.6	46	23	Railroad bridge destroyed
Neiderense	3.7	38	19	Large railroad bridge destroyed
Neheim	8.1	33	16	Road bridge destroyed
Wickede	16.0	28	13	Road bridge destroyed
Fronenburg	23.6	26	10	Railroad and road bridge destroyed
Schwerte	38.0	25	8	Bridge damaged
.....	65.0	24	6	.....
Mouth of Ruhr	98.0	23	5	.....

The information referred to above was utilized by U. S. Army Engineers in estimating the probable effects that might have been caused by enemy demolition of the Schlucht dam located on a tributary that joins the Rhine River approximately 40 miles up-stream from Bale, Switzerland. The Schlucht reservoir has a capacity practically equal to that of the Mohne reservoir, and the average slope of the Rhine River above Bale conforms closely with the average gradient of the Ruhr River. By taking into account the relative valley storage characteristics of the two rivers, and the effect of the several run-of-river hydro-electric dams below the Schlucht reservoir, the probable height and velocity of flood wave that might have been caused at various points on the Rhine by demolition of the reservoir were estimated. It is interesting to note that the conclusions reached by this analogy checked very closely with those obtained from calculations and model studies conducted by French Engineers in a hydraulic laboratory of Neyret-Beylier et Piccard-Pictet firm at Grenoble, France. The very excellent model studies conducted by the French for the American

Armies are reviewed in an article by Lt. Colonel Stanley W. Dziuban in the May 1946 issue of the *Military Engineer*.

#### SPOTTING HURRICANES AND THUNDERSTORMS BY RADAR

Among the most spectacular developments of the war, radar promises far reaching and valuable service in scientific and commercial fields during peace. The possible applications of this new tool seem almost boundless. The recent success of the Signal Corps in contacting the moon by radar indicates that literally the sky is the limit. The ability of radar to chart the path accurately and reveal the shape and progressive changes in hurricane storms is perhaps of more immediate interest than the "moon" experiments to hydraulic engineers who are responsible for the development of design criteria, or the planning and operation of navigation and flood protective facilities near the Gulf Coast or Atlantic Coast areas. The potentialities of radar in this connection were clearly demonstrated by observations by the Army Air Force Center radar station at Orlo Vista, Florida, during the hurricane of September 1945. This work is described by Mr. S. R. Winters in a paper entitled "Spotting Hurricanes and Thunderstorms by Radar," published in the March 1946 issue of *Radio News*. A summary from this paper will give some conception of the immediate possibilities of radar as a working tool in weather and flood prediction, as well as its value in research.

As early as August 1943, Army radar technicians, noting curious "ghost echoes" on their radar scopes, were able to attribute them to thunderstorms. This led to a study of the phenomenon, and Army Weather observers soon learned how to use radar to plot storms. When the violent hurricanes of September 1945 struck the Florida peninsula near the A.A.F. weather radar station, an opportunity was provided for observations resulting in new findings about the nature of hurricanes. Throughout the hurricane the general shape of the disturbance was plainly viewed on the microwave set, and photographs were obtained at approximately 15-second intervals for record.

To plot the path of the hurricane, the radar equipment consisted of a 30-foot radar antenna mounted on a tower close by, and two electronic sets of the latest Army Air Forces design. One scope or

screen on the radar apparatus—the same device employed on bombers for spotting enemy targets at night or in fog—was used as a height finder. Its pattern took the form of an irregular line oscillating or moving to and fro from top to bottom of the radar scope. The other was a microwave set, or finger-length radar outfit, with an electronic radius sweep of 220 miles and capable of affording advance warning of an approaching storm.

It was on the morning of September 15 when the microwave set first intercepted returning impulses or “echoes” from southern Florida. Amidst a speckled blue light on the round, black radar scope, line squalls in concentric arcs were recorded as approaching northward in the Florida peninsula. By 8 o'clock that night, the radar screen indicated that each succeeding concentric arc had a somewhat smaller radius of curvature, and at exactly two minutes to 10 o'clock the center of the atmospheric disturbance was identified, beyond a peradventure, as 30 miles northwest of Miami. It was estimated that the “eye” of the hurricane was travelling at nine miles an hour along a curved course leading directly toward the radar station. Velocities in the periphery of the rotating disturbance were determined as 100 miles per hour from anemometer observations in the storm area.

The radar crew's reports show that the general outline of the storm was unmistakably clear on the microwave set, the impulses or radar energy being reflected in a superb manner through the rain accompanying the hurricane. Its shape was that of the numeral six, with clockwise “tails” having a spiral effect. At one o'clock on the morning of September 16, six distinct “tails” were visible, three of which were detached and traveling northward in advance of the storm's center. These “tails” were rain-carrying storm clouds, or line squalls, eight to ten miles in width and from three to five miles apart.

At 3:45 a.m. September 16, the “eye” of the storm was in juxtaposition of the radar station, having passed by ten miles to the westward. This “eye”, the low-pressure area in the center of the disturbance, measured 12 miles in diameter. The absence of impulses or echoes on the radar screens indicated that there was no rainfall in the immediate vicinity of Orlo Vista. The height-determining radar outfit indicated that the thick cloud deck enveloping the eye of the storm extended to an elevation averaging 18,000 feet.

The violence of the storm had diminished appreciably as it traveled overland. The radar scopes continued to intercept telltales of the hurricane as it moved in a northeasterly direction toward Jacksonville. The entire progress of the hurricane, in its gradual curve up Florida, had been accurately plotted by radar-photographs taken at 15-second intervals. Results of the trial indicate that the use of radar may revolutionize methods of forecasting and plotting these destructive storms. It has been demonstrated that a stationary radar or television screen can survey the location, extent, intensity, and direction of thunderstorms, and similar violent atmospheric disturbances within a radius of 100 to 200 miles.

In this connection, of interest is the recent announcement that the Army and Navy have established a special program of air reconnaissance in the Caribbean area to locate and trace hurricanes by the aid of improved radar equipment carried in planes. The planes will fly near the hurricane disturbance and maintain a continuous surveillance of its movements by use of radar, without flying into the danger area. By this auxiliary use of aircraft, the history of the hurricane can be traced practically from its genesis, and warning to shipping and shore installations can be assured safely in advance. Thus the radar-equipped plane will offer a service in respect to hurricanes somewhat analogous to that performed by the Coast Guard in locating icebergs and similar dangers to shipping in the Northern waters.

Improvements in equipment and technique are, of course, looked forward to. Several technical papers relating to the use of radar in the plotting and prediction of thunderstorms were presented at the annual meeting of the American Geophysical Union in Washington, D. C., 27-29 May 1946, and will be published in the regular *Transactions* issued by that organization.

#### HYDROGRAPHIC SURVEYS BY ECHO-SOUNDING

Another revolutionary development of interest to hydraulic engineers concerned with river and harbor improvements is the adaptation of echo-sounding devices to shallow-water hydrographic surveys. The ability to measure accurately, quickly and economically the depth of water in selected sections of a river, impounding reservoir, or harbor is of far-reaching importance in the design of regulating structures and operational facilities. The combination of

echo-sounding and radar techniques permits such measurements to be made in an expeditious and satisfactory manner.

### *Hydrographic Surveys by Conventional Methods*

A hydrographic survey is a three-dimensional survey in which a sounding represents a vertical measurement of the depth of the water, which must be located in the horizontal plane by two coordinates. A knowledge of the depth is useless without the geographical position at which the depth is measured, or its relative position with reference to the adjacent landmarks.

The problem of hydrographic surveying is two-fold, one part consisting of the various methods of measuring the depths of the water and the second part consisting of the measurements to determine positions in the horizontal plane. The former are termed "soundings" and the latter is called "position finding" or the horizontal control of the survey. It may be assumed that the difficulties and inaccuracies of conventional methods are appreciated by this audience; the improvement in hydrographic surveying made possible by recently developed apparatus will be of interest to all.

### *Surveys with Supersonic Sounding Equipment*

The principle of sound travel through water and its reflection or echo from obstacles in its path has only been recently suggested and used as a method of determining depths in water. Sounds in fresh water travel at the rate of approximately 4,800 feet per second and for the various applications of sound in water, including hydrographic surveying, sound velocity varies but slightly from season to season. These variations can be determined and due allowance made in survey work. Soundings may be obtained while the boat proceeds at any speed and for the depth of which the apparatus is capable. Echo-sounding is the method used to measure the depth of water by determining the time required for sound waves to travel, at known velocity, from a point near the surface of the water to the bottom of the river or reservoir and return. Echo-sounding equipment is designed to produce the sound, receive and amplify the echo, measure the intervening time interval very accurately, and convert this interval automatically into units of depth measurement, such as feet, fathoms or meters. Every echo-

sounding instrument is composed of three principal parts which create depth measurement, (1) the acoustic transmitting unit or sound producing part, and the source of energy to operate this unit; (2) the acoustic receiving unit and the echo amplifier; and (3) the registering device, including a motor whose speed is controlled, an index and depth scale, and the necessary keying circuit.

Sonic waves advance in a spherical front and cannot be projected in a single direction. This, in addition to the fact that sonic frequencies are audible, is a disadvantage in hydrographic survey work. Ordinary water sounds such as the break of waves, wash of water on submerged rocks, and sounds from engines and propellers of vessels are audible on the hydrophones used in the sonic systems, and this causes the extraneous sounds to register with, or to the exclusion of, the depth echo.

Supersonic waves are above auditory preception. This, together with the fact that the supersonic waves are in the form of a highly directional beam, accounts for the general use of supersonic echo-sounding equipment in hydrographic surveys. The higher supersonic frequencies make possible more depth soundings per unit of time and thus expedite survey operations. Because of the shorter wave lengths the supersonic system can be used in shallow depths. The supersonic depth-recording units manufactured by commercial firms differ in details of design, but are, without exception, simply automatic devices to measure accurately very short intervals of time. The units automatically convert the time interval into feet or fathoms graphically on a graduated scale. This type of equipment is manufactured in either permanently mounted or portable form.

Supersonic-echo-sounding equipment has been used on almost all recent hydrographic surveys made under the jurisdiction of the Lower Mississippi Valley Division and the Mississippi River Commission, and the results have been very satisfactory. These surveys are made on the Mississippi River and its tributaries but the equipment may be used equally well for sediment surveys on other rivers or on existing reservoirs.

A machine of the non-portable type is very sensitive and will depict salt water under fresh water, recent fill on the bottom of the river or any heavy substances above the bottom of the river together with the various layers of material for some distance be-

low to the actual hard bottom of the stream. It will measure soundings about 200 feet in depth and with a skilled crew should measure with an accuracy of 0.3 foot in 100 feet. Units of this type are now installed on all of the channel patrol boats of the Mississippi River Commission, sounding the river from Cairo, Illinois, to the Gulf of Mexico and on some of the heavier sounding boats on hydrographic surveys and discharge work in the New Orleans Engineer District. Up to the present time they have required very little maintenance and have given excellent results. On channel work, the boat proceeds at full speed while taking soundings and thus saves considerable time in a year's operation. Also the soundings are accurate and a permanent record is maintained in the files.

The Mississippi River Commission intends to use the portable units to sound reservoirs and to determine changes in the bottom elevations from which a record of sedimentation can be secured. The portable units have given very little trouble in the field and practically no sounding is done now in the Lower Mississippi Valley Division with the old lead-line method.

In actual operation, the non-portable units require one man when cross sections are being sounded. An additional man is required to operate the "fix" button to show the location of the sounding on the chart. All operating power is furnished off the electrical generating sets on the steamboat or diesel boat. Various types of personnel operate these units, from inspectors to pilots on the steamboats. Routine repairs are usually made by the radioman on the large boat. A portable unit also requires one or two persons to operate it depending on the type of work; however, power to operate the unit is usually supplied from a 12-volt battery. The battery may be charged on the boat that operates the sounding equipment or additional batteries can be used, one being in use, one held for emergencies, and one being recharged at any filling station.

Reliable results are secured from boats running upstream or downstream at full speed. The only feature that must be carefully observed is that the installation of the oscillators is properly made. If air flows under the oscillator, the echo-sounding device will not record the depth of water. In normal cases there is no trouble from this condition on a model hull boat, but the Mississippi River Commission has been unable to make an inboard oscillator installation function satisfactorily on a flat bottom boat.

Soundings are located in various ways either with plane table or a sextant or a transit. Radar promises a more satisfactory method of sounding location than now commonly used, as will be discussed later. For cross sections on revetments in the Mississippi River or for rivers of normal width, the Commission personnel have a device for measuring the distance from a known point on the river bank and recording the "fixes" or "locations" on the actual cross section graph at 10-foot or 20-foot intervals or at any selected points for comparison with previous work while the soundings are being recorded on the paper. This is quite a time saver, as the distances are all actually located positively from a known point using a piano wire for a measuring unit.

A usual objection to the echo-sounding equipment is the original cost of installation. Also the survey personnel have to change their methods of making and recording the survey data. The question is invariably asked, why spend as much as \$9,000 on echo-sounding equipment when a hand lead-line can be made for a couple of dollars and a man can be hired for \$75.00 per month to do the sounding. In answer to this question: (1) the accuracy of the results is not comparable, (2) the echo-sounding unit furnishes a permanent record for later analysis and (3) a trained crew can do from 6 to 8 times more work for a given working season with the echo-sounding equipment. A cross-section of the Mississippi River in low water can be secured by the echo method in 3 minutes with soundings recorded at the rate of 200 per minute and a cross-section that would require one hour or more to secure accurately in high water by the old methods can be sounded in about 6 minutes with the present echo device.

One final caution: The echo-sounding device is mechanical and will record soundings, whether in adjustment or not; therefore, a high-caliber, trained crew is necessary to operate these units if accurate work is expected in the field survey.

Vastly improved echo-sounding equipment has been developed by the Navy during the war. Details of this equipment are not immediately available, but it is known that the equipment is very much more compact than that now commercially available and is suitable for use in small boats.

*Use of Radar for "Position Finding" in Hydrographic Surveys*

The recent developments of precise supersonic echo-sounding equipment has greatly accelerated the sounding procedures, but the method of positioning soundings has lagged far behind. The continuous graphical recording of depths by the improved fathometer at a rate of 200 per minute at a boat speed up to 7 knots has necessitated the improvement in methods of positioning. The great need of an automatic positioning recorder has been felt for some time, but until the advent of radar, no successful equipment has been developed.

With these thoughts in mind, experiments were conducted in the Galveston Outer Bay and jetty channels under the supervision of Major W. W. Vance, Chief of Operations Division of the Galveston District of the U. S. Corps of Engineers.

Positioning of soundings had been accomplished in the past by means of two sextant angles read aboard the survey boat between prominent landmarks on the shore. An effort to speed up this method by means of a sextant angle grid was a definite improvement, but the fact that the work could be delayed by bad weather and poor visibility was another difficulty that had to be overcome. Maximum calm periods seem to exist in the five jetty and outer bar channels of the Galveston District when the visibility is obscured by fog or land haze.

Very little was known about radar or its possible use in tracking a survey boat, but from general descriptions in magazines it seemed that radar equipment was developed for a similar type of work. Through informal contacts with the radar officer at the local harbor defense headquarters, an experienced radar crew and a Mobile Radar Unit SCR-584 was obtained for experimental work in tracking a survey ship while sounding in the Galveston Entrance Channel.

The Mobile Radar Unit SCR-584 equipment consists of a large steel van with all equipment and controls mounted inside. The antenna is lowered inside the van roof when traveling, and raised to a position above the roof when in operation. The antenna will automatically position on a ship and track it automatically. Readings for range, elevation, and azimuth are obtained from dials. A small telescope is mounted on the antenna and may be used to assist

in the initial orientation of the unit. The operating power is furnished by a portable M-7 generator.

Radio communications are maintained between the radar van and the survey ship for control information and to direct verbally the ship's course from plotted course data.

In experimental tests conducted in November 1945, the mobile radar unit was set over a U. S. G. S. Monument "Jacinto 1933" located near the land end of the south jetty of the Galveston Entrance Channel. This equipment was then oriented at true north as 0 mils azimuth by means of four definite and prominent landmarks. The correct azimuths and ranges for these four points were computed and used in orienting and checking the orientation of the radar unit.

Two charts were prepared of the area to be covered by the survey. One chart known as the Sextant Grid Chart was prepared so that two angles obtained by two sextants aboard the ship to definite control points could be quickly plotted without use of protractors. The second chart was drawn to the same scale and as a perfect overlay. A grid on this chart with azimuth in mils and range in yards allowed quick plotting of the radar data at the land station. Ship to shore radio was used so that sextant readings and radar readings could be obtained at the same instant. Overlaying these charts on a light table after completion of the day's experimental courses showed better coincidence than was first anticipated.

The results obtained were discussed by the Galveston District Engineer's personnel with radar authorities at the Army Air Base at Orlando, Florida, who were greatly interested in the successful possibilities of the new method. They reviewed the equipment used and made suggestions on the use of improved attachments to increase the accuracy as well as the automatic plotting facilities of the equipment.

In the installation and use of this improved equipment, the survey boat will be equipped with a recording fathometer as manufactured by the Submarine Signal Company to the specifications of the Office, Chief of Engineers. This fathometer incorporates all the features which have been developed for the indicating units and a number of other features which field experience has shown to be necessary to meet the survey requirements of the Corps of Engineers.

A Responder Beacon will be mounted on the mast of the survey boat and will give off a definite signal when activated by the radar beam.

Ship-to-shore radio contact will be maintained for supervision by the party chief on the survey boat.

The SCR-584 Radar van will be set over a control monument and oriented at true north as 0 mils azimuth as in the experimental tests. A Miller Precision Plotting Board attachment will be placed in the radar van, and its arm oriented with a previously prepared chart of the area to be surveyed. Test shots will be obtained on the jetty lights or other control landmarks in the area.

The end of this plotting arm is equipped with a "pip squeak" attachment which will burn a pin hole in the chart when activated by radio by a trigger mechanism in the hand of the fathometer attendant aboard the survey ship. The attendant can mark a number or letter on the fathograph and inform verbally by radio so that the radar attendant at the land station can put a similar marking on the pin hole on the chart. In actuality, the profile of the depths of water is plotted by the fathometer aboard ship while the land radar station draws a plan of the course traveled.

This work can be conducted at night or during times of no visibility due to fog or land haze.

It is anticipated that additional experimental work will be performed with this type of equipment so that a navy radar set mounted on the survey ship will do the positioning with reference to land control points and in this way make the hydrographic survey boat self-contained. Experimental work will also be performed in land survey work such as triangulation, and laying out large reservoir areas over distances greater than eye range.

The utilization in peacetime of wartime-developed radar equipment to position automatically a survey boat and plot that position on a chart as the boat proceeds along the survey course will bring the positioning of soundings up to date with the automatic recording of the soundings by the fathometer. It is believed that the development of this method will save large sums of money, valuable time, and effect a decided improvement in results.

DETERMINATION OF DEPTHS IN SHALLOW WATER BY AIR  
PHOTOGRAPHY USING COLOR FILTERS

*General*

The value of air photography for map making and for the study of land detail was appreciated before the war, but the study of underwater detail from air photographs had received little attention. The landing at Tarawa, where the danger of a submerged reef had not been accurately assessed, emphasized the need for a new method of determining depths in shallow water. The British Army Photographs Research Unit started work on development of the procedure in September 1944 under orders of the Air Directorate of the British War Office, and has published certain information on the techniques in a booklet entitled "The Determination of the Depths and Extinction Coefficients of Shallow Water by Air Photography Using Colour Filters," by Major J. George Moore, M. A., December 1945. Over 10,000 photographs were taken during the extensive trials. Similar work has been carried on by the U. S. Army, but results of the studies have not yet been published. Inasmuch as the techniques involved have great promise in application to rapid surveys of rivers, lakes and harbor areas, and literature thereon is very difficult to obtain for general distribution at the present time, there is presented herein a relatively detailed summary of the method and results obtained by the British in trials presented in the reference previously cited.

The procedure developed has been referred to in the services as the "Transparency Method", and may be described briefly as follows:

If a sandy beach is photographed vertically from the air through a color filter, its apparent brightness is found to vary in a simple way with the depth and clarity of the water over it; if the clarity (or the extinction coefficient) of the water is known, the depth of water can be determined by measuring the relative brightness at different points on a single air photograph. If it is not known, the measurements may be made on a pair of photographs taken simultaneously through two special color filters and, since a relationship between the two extinction coefficients can be assumed, depths can be determined from the photographs alone without any other source of information. This is done graphically by means of

a special Calculator, and from the results the clarity of the water can also be assessed. In average coastal waters depths down to 20 feet or more may be determined to an accuracy of  $\pm 10\%$ . Similar accuracy can be obtained to depths exceeding 50 feet or more under reasonably favorable conditions.

A "brightness profile" is defined as the curve produced by plotting, as ordinates, the relative brightness of points on the seabed against their horizontal distances from the waterline; these brightnesses are measured in a nearly vertical direction from the air. Because the intensity of light transmitted by a given depth of water varies with wavelength, the shape of a brightness profile will depend on the wavelength of the light observed; therefore, a comparison of the shapes of a pair of brightness profiles prepared from photographs taken simultaneously through two contrasting filters (which pass only light of certain wavelengths) enables depths to be determined when absolute values of the extinction coefficients are not known.

The brightness of any point on a "brightness profile", as observed vertically from the air, is due to:

- a.* Light from all sources scattered by atmospheric haze in the column of air between the sea surface and the observer.
- b.* Light reflected vertically upwards by the sea surface.
- c.* Light scattered vertically upwards by particles within the water.
- d.* Light reflected from the seabed to emerge vertically from the sea surface.

The intensity of the light scattered by atmospheric haze will depend upon a large number of variables, including the sun altitude, the amount of cloud, the height of the observer and the type and density distribution of the haze. To reduce the effect of haze on the brightness profile, air photographs are taken when haze is at a minimum, and from as low an altitude as requirements permit. Although some selective scattering by the atmosphere is unavoidable, application of correction factors permits satisfactory operations under average conditions from altitudes of 5,000 to 20,000 feet.

Reflection of light from the sea surface depends primarily on

the sun altitude, the amount of cloud and the size of waves. Waves or swells affect the brightness profile in two ways: they increase or decrease the length of water column through which the light is passing, and they also alter the surface reflection to an extent depending on the angle of the water surface, the sun altitude and the amount of cloud in the sky. Wave or swell effects may be distinguished from changes in the gradient or reflectivity of the seabed by comparing brightness profiles constructed from overlapping photographs. If the disturbance is found to be moving relative to the horizontal scale of the profile, it may be ascribed to wave motion. Its amplitude will depend on the depth and extinction coefficient of the water and will therefore vary with the filter used. Provided the wave motion shown on the profile is of small amplitude, it can be removed by drawing a mean curve through the points concerned. The analyses of overlapping photographs may be adapted to the study of wave action.

Variations in the extinction coefficient may result from changes in pollution of the water, suspended matter or air bubbles caused by wave action and turbulence, diatom outbursts, or mixing of different water types at the mouths of estuaries. It has been found that these effects on determinations of depths are negligible if water is calm and a few feet deep. Appropriate corrections in calculations enable depths and extinction coefficients to be determined from this point onwards. Analyses of variations in extinction coefficients at a given location offer a means of determining pollution variations.

After passing through the water, the light reaching the seabed will be partly diffuse and partly parallel, the proportions varying over a wide range; the bed material will act as a diffuse reflector, the fraction reflected varying from 0.50 to about 0.05, depending on the color and texture of the bottom and the wavelength of the light considered. A sudden change in reflectivity of the seabed will produce a discontinuity in the profile. A gradual change will alter the rate of curvature of the profile, and will appear as a change in the extinction coefficient or in the bottom profile. Generally, changes in bed-material reflectivity are immediately apparent from examination of a negative taken through a green filter. If the seabed is not of uniform material, it is necessary to break the

profile into short sections of approximately uniform reflectivity, and to analyze each section separately.

### *Photographic Equipment*

Two cameras were used in the majority of trials, one equipped with a Wratten 56 (green) filter and the other with a Wratten 27 (red) filter. The lenses selected varied in focal length from 8 inches to 36 inches, and each pair of cameras was matched as closely as possible for focal length. They were mounted in the aircraft with their optical axes parallel. Both cameras had focal-plane shutters and were fitted with sensitometers in order that the relationship between the exposure given to each negative and the density produced after development could be determined. The sensitometer consisted of a calibrated step wedge which was evenly illuminated along its length by an electric lamp on each operation of the shutter.

### *Operating Conditions*

Experience showed that certain well defined meteorological and sea conditions were essential. This was not found to be a serious disadvantage, as so much material was produced from a single sortie under good conditions that frequent sorties were unnecessary.

The sky should either be free from cloud, or fully covered by high cloud. Generally, the sun should be between  $30^{\circ}$  and  $50^{\circ}$  above the horizon. Haze should be at a minimum.

Apart from navigational difficulties a wind invariably reduces the value of the photograph by:

- a. Increasing the amplitude of waves on the water surface and so distorting the brightness profile.
- b. Stirring up particles from the seabed.
- c. Causing local variations in the reflectivity of the sea surface.

Without exception, the best photographs for interpretation were taken on days of low or no wind at the sea surface, although useful results have been obtained from photographs taken with a 10—15-m.p.h. wind blowing off the land.

Flying height is determined by the focal length of the cameras used. A scale of  $1/8000$  is desirable for the photographs since a

larger scale, apart from giving insufficient cover, may show too much wave detail and a smaller scale causes errors due to less accurate location of points whose densities are being compared on the "red" and "green" negatives.

### *Interpretation of Photographs*

Three methods of interpretation are suggested in the report by the British Army Photographic Research Unit:

I. Visual examination of prints without measurement.

II. Construction of brightness profiles from density measurements on the original negatives.

III. Construction of brightness profiles from comparative tone measurements on specially prepared prints.

I. VISUAL EXAMINATION OF PRINTS: The prints may be made by contact printing on a normal grade of printing paper; the printing exposure should be so adjusted that neutral-colored objects above the waterline are slightly under-exposed and of approximately equal tone on the "green" and "red" prints.

Two prints should be prepared from each infra-red negative:

a. One normal print recording the maximum detail on the land; on this print the water will be completely black and the exact waterline will be sharply silhouetted against the land areas.

b. One very under-exposed print, showing almost no land detail but the maximum detail under the water.

The following observations can be made from the prints:

a. The "green" prints show underwater detail to the greatest depth; under favorable conditions detail might be visible at 50 feet or more.

b. The "red" prints emphasize the configuration of the shallow areas and enable estimates of relative depths to be made in shallow water. Detail is never likely to be visible below 20 feet.

c. The change in tone and in sharpness of outline of the rocks as the water becomes deeper gives an indication of the clarity of the water.

d. Infra-red prints can be used either to show the exact position of the waterline or to assess the depth of very shallow water. On these prints seaweed on or just below the surface is very evident because of its high reflectivity for very deep red light, causing a contrast against the dark background of the water.

It is unfortunate that copies of photographs illustrating the many applications of the method are not immediately available in form suitable for publication. These photographs show variously submerged pollution in coastal water, seaweed beds, the effect of headlands on the clarity of coastal water, the underwater configuration of certain beaches governed by wave action, and changes in visibility of the seabed under various meteorological and sea conditions.

II. CONSTRUCTION OF BRIGHTNESS PROFILES FROM DENSITY MEASUREMENTS ON ORIGINAL NEGATIVES: The procedure adopted for construction of brightness profiles from density measurements on the original negatives involved the analysis of a pair of "green" and "red" negatives. The scale of the negatives was determined by comparison with a reliable map or from camera focal length and flying height. A line for the profile study was then selected, and points thereon designated by pin points. Distances to the points from the shore line were measured graphically, and depths at the respective points were determined by comparison of film negative densities at each point with densities on the calibrated sensitometer scale. Special comparators and calculators permitted these measurements to be made accurately.

III. CONSTRUCTION OF BRIGHTNESS PROFILES FROM COMPARATIVE TONE MEASUREMENTS ON SPECIALLY PREPARED PRINTS: Brightness profiles from comparative tone measurements are constructed from prints rather than negatives. The method is about twice as fast as the density measurement method, but generally less accurate. A paper comparator is prepared photographically in steps with small tone differences that are calibrated by comparison with a print from the sensitometer strip, and this is used for determining depths at various points on the selected profile line by comparison of tones.

### *Comparison With Existing Methods*

It has been shown that, if the water is calm and fairly clear and the photographic conditions are properly chosen:

a. The underwater detail can be recorded over large areas of the seabed to depths exceeding 30 feet.

b. Depths can be determined over light colored beaches with an accuracy better than 10% over a depth range exceeding 20 feet. Independent depth measurements are not required, but, if available, they permit the elimination of one camera or can be used as a check on the results obtained with two cameras.

c. The clarity or state of pollution of the water can be assessed in terms of mean extinction coefficients; these measurements can be made practically simultaneously over large areas.

### *Distribution of Underwater Detail*

There is probably no satisfactory alternative method to air photography for recording the detailed distribution of rocks, weeds, sandbars, obstacles, and similar detail of the seabed.

### *The Determination of Depths and Gradients*

The peculiar advantage of the transparency method for determining depths or beach gradients in shallow water lies in the fact that a large number of records can be made over an extensive area within a very short time interval; the records can then be examined at leisure and the effect of factors such as tides, currents, etc., which vary with time can be compared over the whole area. Alternate methods of recording depths, for instance by line or echo sounding, will give more accurate results over greater depth ranges, but the records can not be obtained over a large area at anything like the speed permitted by air photography, nor are they automatically related to the geological configuration of the seabed.

The operational method of depth determination, known as the "wave velocity method," is complementary to the present method as it can be used when the sea conditions are unsuitable for photography of underwater detail; but it can not be used when the sea is calm or if the coastline is strongly indented, conditions most suited to the present work.

Stereoscopic photographs have been used to determine the depths of shallow water; suitable conditions may however be difficult to obtain.

### *The Measurement of Water Clarity*

All the existing methods of evaluating clarity are based on some form of measurement at or below a point on the water surface. They cannot be used to give information over an area, and therefore there is at present little knowledge of the effect of tides, currents, sun altitudes, seasons, and similar factors on the clarity of coastal water. The direct or indirect dependence of marine life on photosynthesis is, however, well known, and therefore it is considered that the present method provides a new and important tool for the marine biologist. Whether or not the extinction coefficients determined from air photographs are capable of exact physical explanation has not been determined, but they appear to be directly related to the clarity of water, and are extremely sensitive to the effects of pollution.

### *Possible Scientific and Industrial Applications*

Among the many possible uses of the "Transparency Method" may be included:

*a.* Uses based on photography of underwater detail:

Study of the geology and marine biology of the seabed.

Detection of submerged obstacles to navigation, including reefs, wrecks, etc.

The control of industrial pollution.

Archaeological study of submerged areas.

*b.* Uses based on determination of depths and gradients:

The preparation of charts of shallow water areas.

The control of erosion and deposition on beaches, and in navigable channels and harbors.

Study of the effects of current and tides on the formation and movement of sandbars, beach gradients, etc.

Research on wave motion and tides in shallow water.

Recording depths of water for engineering purposes. (This will be particularly valuable in relatively inaccessible areas).

c. Uses based on the determination of water clarity:

Study of the effects on marine life of light of various wavelengths and intensities.

Control of pollution.

Identifying water types and recording coastal currents.

Planning engineering operation (e.g. diving and salvage) in which submarine visibility is important.

## CONCLUSION

It is gratifying to conclude from the few examples cited above and from subjects currently presented in other papers, that in this Atomic Age, in which all branches of science and engineering have made great strides, the hydraulic engineer retains his position as a progressive and essential element in the course of technical advancement.

## ACKNOWLEDGMENTS

It is desired to acknowledge with thanks the several contributions of information and assistance that made this paper possible. Special appreciation is expressed for the assistance of Mr. A. L. Cochran, Hydraulic Engineer, Office of the Chief of Engineers, in assembling the manuscript. Valuable aid was rendered by the Beach Erosion Board, and the Engineer Board of the Chief of Engineers' Office; the Engineer School, U. S. Army, Fort Belvoir; the Galveston District of the Southwestern Division, Corps of Engineers; and the Waterways Experiment Station, Corps of Engineers, Vicksburg, in furnishing publications and special reports necessary as sources of information. The nature of the paper has required abstracts from articles by several different authors that have been referred to herein. It has been the writer's primary purpose to call attention to certain new developments in equipment that seem to warrant careful consideration of hydraulic engineers. Little originality is claimed by him for the contents of the paper.

Attention is invited to the accompanying bibliography for sources of more detailed information on topics discussed herein.

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