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FOURTH INTERAGENCY CONFERENCE ON HYDRAULICS LABORATORY TECHNIQUES AND INSTRUMENTATION

by

U. S. ARMY COASTAL ENGINEERING RESEARCH CENTER
WASHINGTON, D. C.

SEPTEMBER 15-16, 1964

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The meeting was convened in the CERC conference room at 8:00 AM, 15 September 1964, with Mr. J. H. Douma, OCE, presiding. The conferees were welcomed to CERC by Col. F. O. Diercks, Director. Mr. Douma appointed Mr. F. B. Campbell, WES, as recorder. Dr. Keulegan and Mr. Campbell joined the conference at 8:30 AM being late because of a misunderstanding regarding housing and transportation. The list of attendees is attached as Appendix 1. The agenda which had been furnished to participants is Appendix 2.

RECORD OF AGENDA DISCUSSION

1. WAVE ACTION FACILITIES AND TECHNIQUES

1. a. Techniques for Measuring and Controlling Bore Waves in Canals - Wave Analysis. Mr. Martin, USBR, introduced the subject and described a problem of waves in the forebay canal at San Luis Forebay Dam created by pump stoppage due to power failure. Study was made of the length and elevation of a side channel weir to adequately dampen these waves. Discussion was concerned with types of wave gages. USBR had used variable capacitance depth gages but CERC stated they use resistance gages because they have found that capacitance gages clip the crest off of waves.

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b. Wave Making Facilities and Techniques. This subject was introduced by Mr. Brownell, DTMB. An important phase of the work at the Model Basin consists of the study of sea keeping characteristics of various facilities. Mr. Brownell enumerated five types of wave making machines: plunger, flap, piston, cylinder and pneumatic. The basic mechanisms of these types has not changed substantially through the years. The model basin is presently concerned with transient and irregular waves. They employ an electro-hydraulic drive. The wave is programmed by a magnetic tape system. Mr. Brownell believes that a tape is best suited for this type of program.

Common methods of measuring wave heights at various activities include resistance probes, capacitance probes and sonic type probes. The first two are subject to calibration difficulties because

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of dirt accumulating on the elements. The Model Basin has also experienced breakage of the probe wires at high tow carriage velocities. The sonic type probes use a pulse which is reflected from the water surface. The types in use at the Model Basin are the capacitance and sonic probes.

A general discussion of wave breakup followed. Mr. Brownell pointed out that one problem area concerns the breakup of short waves of low amplitude with the attendant short length of travel in long basins. An example would be waves with a length of 10 ft or less and with a period of less than 2 seconds. There are now much more data taken in tests and hence more work in the reduction of data. However, the use of electronic equipment has simplified this problem.

Mr. Douma asked whether the Model Basin had studied wind generated waves in the laboratory and Mr. Brownell answered in the negative. Mr. Murphy noted that wind generated waves are currently being studied in Europe.

Mr. Caldwell, CERC, presented a very well arranged talk on wave making facilities. He projected sketches on the screen to illustrate his remarks. Mr. Caldwell's prepared discussion on this subject is attached as Appendix 3. Mr. Duke asked about the type of motor being used to drive the large wave machine. Mr. Caldwell replied that they used a direct current motor with magnetic control.

c. Methods of Reproducing Tsunamis. Mr. Theus, NPD Hydraulic Laboratory, opened the discussion of tsunamis. He emphasized that tsunamis are very long waves with low amplitude and traveling at a very high speed. The model of Hilo Harbor which is being constructed in Hawaii was briefly described. An interesting compilation of historical data on tsunamis occurrences at Hilo Harbor was presented. Mr. Theus asked whether CERC or DTMB had had experience in this area. Mr. Douma called on Dr. Keulegan who has been extensively involved in the design of the Hilo Harbor model to present his views.

Dr. Keulegan gave an excellent blackboard talk on the subject of reproducing tsunamis in hydraulic models. There are two types of such phenomenon, the single wave and the successive wave. A mechanical type of apparatus was described when a barrier between two bodies of water at different levels is suddenly removed. Immediately afterwards a positive wave moves over the lower water surface and a negative wave moves through the upper water surface. In dealing with the theory, Dr. Keulegan said that an assumption must be made for bottom friction if the wave approaches shallow water. He indicated that the method of characteristics can be used. The mechanical type of tsunamis generator requires very large power.

Dr. Keulegan also described a pneumatic type tsunami generator. In this case, subatmospheric pressure variation is introduced in a chamber behind a bulkhead. This has been treated successfully at the WES with a single bottom aperture of the bulkhead. A graph showing the variation in total head and pressure behind the bulkhead was sketched. It was noted that the pressure actually fluctuates slightly in the beginning. Pressure control is not necessary for single waves. Dr. Keulegan sketched his concept of the final design for the tsunami generator and indicated the type of calibration needed before actual model studies are undertaken.

In the actual use of the tsunami generators, it is proposed to use several different machines on a semicircular plane facing the harbor embayment. It will be necessary to use absorptive materials between the machines and the harbor. Various types of filters are currently under study. Mr. Caldwell posed several questions to Dr. Keulegan and a considerable dialogue developed. Dr. Keulegan stated that the model must be distorted in order to account for the effects of viscosity.

2. CLOSED CONDUIT FLOW MEASUREMENTS

2. a. Cavitation Measurements. Mr. Martin, USBR, introduced the subject of cavitation. The Bureau has been making use of an Allis-Chalmers study of the cavitation on butterfly valves. A combination of audio and visual criteria is used to determine the existence of cavitation. The Bureau has attempted to minimize cavitation by introducing air through the butterfly valve stem to the downstream face of the valve leaf. Also air has been admitted through a tube extending through the valve body to a position near the downstream face of the leaf.

Mr. Elder asked whether the vibration of the butterfly valves had been studied. Mr. Martin replied affirmatively and said that accelerometers had been used. Mr. Campbell asked whether the Bureau proposed using butterfly valves for outlet works. Mr. Martin replied their current use is for pipeline turnouts. The laboratory models at the Bureau have been of prototype size. Mr. Martin referred to a USBR Laboratory report on multiple orifices, HYD-519, entitled "Progress Report on Hydraulic Characteristics of Pipeline Orifices and Sudden Enlargements Used for Energy Dissipation." Mr. Theus said that they had been studying a 3 ft butterfly valve under 50 ft of head. The problems of both vibration and cavitation are under study.

Mr. Brownell advised that the Model Basin was currently engaged in experimentation on cavitation. They also depend upon visual and sonic observations to determine the existence of cavitation. Hydrophones are used to sense the sound of cavitation in a water tunnel. The Model Basin has experimented with ventilation of the cavity. This process produces an air or gas cavity. Small transducers on a boundary adjacent to the cavity are used for measuring the pressure.

b. Techniques for Measuring Wall Roughness and Boundary Shear-Field Measurements. The subject was introduced by Mr. Campbell, WES. He mentioned that the Corps has been making plaster casts of the wall roughness for some years. The absolute roughness is measured on the casts by using a mechanical device involving an Ames dial. This was described on page 281 of the Seventh Iowa Hydraulics Conference, 1958. It is necessary to traverse the cast several times making readings by the Ames dial. The data are programmed for a digital computer to determine first the regression line of each traverse and then the root mean square of the roughness projections. The absolute roughness is twice the root mean square or standard error. The absolute roughness divided by the diameter of the conduit is a parameter in the rough flow zone of the Moody diagram. Studies at WES of correlation between the Darcy-Weisbach resistance coefficient and the relative roughness confirms the Prandtl-Von Karman rough flow relationships. The Colebrook-White function in the transition zone for high Reynolds numbers can not be confirmed.

Mr. Campbell also referred to the Preston tube technique which was published in the Journal of the Royal Aeronautical Society in 1954. Wall shear in Ft. Randall Tunnel No. 10 could not be determined by Preston tubes because of large projections caused by coal tar runs upstream from the points of observation. It was his opinion that the Preston tube is a valuable device for uniform roughness in the laboratory and perhaps for relatively smooth prototype wall surfaces. Reference was made to a report by Dr. Ippen, et al, on the use of a Preston tube for measuring boundary shear in curved channels. This is a Massachusetts Institute of Technology report No. 43, Oct. 1960. Mr. Brownell said that the Model Basin had used Velometer apparatus equipped with a pressure transducer to measure the boundary shear. Mr. Campbell asked whether the model basin still uses a row of knobs on the prow of model vessels for artificial stimulation of the turbulent boundary layer. The Model Basin generally uses knobs for surface models and sand strips for submerged models. Mr. Campbell asked Mr. Martin whether the Bureau has made any field measurements of absolute roughness in connection with their friction loss measurements. Mr. Martin said that the Bureau is making friction loss measurements on continuous or jointless concrete pipe using pitot tube traverse and isotope techniques. The pipe is produced by a continuous extrusion process which is patented by a private interest. The Bureau is interested in a study of this type of concrete pipe because joints are eliminated and only the wall roughness caused by the process is of concern.

BREAK - 10:25 AM - 10:40 AM

2. c. Techniques for Measuring Boundary Layer Effects in Models. Mr. Martin opened the discussion by again referring to the use of Preston tubes. They have encountered equipment difficulties because of the necessity of measuring pressure differences of 0.001 ft. The Bureau has found a drift in the pressure transducer calibration and only by very careful operation can they obtain a pressure difference of 0.0004 ft.

Mr. Martin stated that the Bureau specifies alignment and smoothness tolerances in the construction of high velocity channels. Plaster casts have been made of a number of canal lining surfaces. Emphasis is placed on inspection of concrete surfaces to insure compliance with specifications.

Mr. Campbell mentioned the difference in the problem of measuring water surface slope in a canal and that of measuring the pressure gradient slope for high velocity pipe. He said that WES had found a much larger scatter of the field data for open channels than for pressure conduits.

Mr. Duke, WES, suggested the use of a differential cell manufactured by the Foxboro Company. Their type 613 DL variable span transducer can measure differences of 0-5 or 0-25 inches of water pressure differential. Information on this device can be obtained from the Foxboro Company, Foxboro, Mass. Mr. Duke said that there is an 18 month delivery time for these instruments and that WES has not yet used the instrument.

Mr. Brownell described some wind tunnel studies where wire mesh was used in the test section to generate a turbulent boundary layer. The wall angle downstream from the test section was then varied in order to study separation phenomenon. Air speeds of 250 ft per sec were involved in the tests.

3. FREE WATER SURFACE PHENOMENA MEASUREMENTS

3. a. Free Surface Vortex-Model and Prototype Similitude. Mr. Martin, USBR, projected on the screen a photograph of a morning glory spillway model. He explained that they had used for guidance a paper by Dr. H. Rouse, entitled "On the Role of Eddies in Fluid Motion," American Scientist, Sigma Xi, New Haven, Conn., Sept. 1963, and that the criteria for a free surface vortex model and prototype similitude developed by G. Holtorf, La Houille Blanche, No. 3, 1964 represent the experience of USBR. Dr. Keulegan, WES, gave a brief blackboard talk concerning the free surface vortex. He emphasized that there are two types of free surface vortex; the Froude number vortex with gravity forces dominant and the Reynolds number vortex where viscous forces are significant. He explained the circulation integral in a description of the Froude number vortex

$$\Gamma = \int vds$$

where; Γ is the circulation integral taken round the boundary of the complete area of flow, v a point velocity and ds a differential of length. The Froude number can then be written:

$$\frac{Q}{\pi a^2 \sqrt{2gH}} = \phi \left(\frac{\Gamma}{a\sqrt{2gH}} , \frac{a}{H} \right) \qquad (2)$$

It was noted that in the case of the Reynolds number vortex the configuration of the approach boundary is important and viscosity should be accounted for in the model. However, in the prototype, viscosity may not be significant and the vortex would then be of the Froude number type.

Mr. Murphy, WES, stated that in his opinion a 1:25 scale model is satisfactory for study of lock culvert intakes provided adequate approach area is carefully reproduced. For such a scale the model will give an indication of vortex formation. He said that in the case of the lock culvert intakes of the St. Lawrence projects a large enough portion of the forebay was not reproduced in the model. No vortex was indicated in the models but a severe vortex developed above the prototype intakes.

Mr. Elder, TVA, stated that they had been using the techniques of the British Hydromechanics Research Association, Harlow, England. Denny and Young presented a paper on "The Prevention of Vortices and Swirls at Intakes" at the Seventh Meeting, IAHR, 1957, Proceedings page C1-1. Several subsequent reports have been made by the Harlow Laboratory. The model tests of the Wilson Dam turbine intake followed this scheme. Mr. Elder believed that a 1:25 model scale was adequate.

Mr. Theus, NPD Hydraulic Laboratory, noted that a time span is required for the vortex to develop in the model. He said that a case had been observed where the vortex eventually forms with a steady flow through an intake. However, for the limited time of filling in the same model, the vortex did not form. Mr. Martin, USBR, stated that observations of a tendency for vortex formation was studied at the Bureau Laboratory in connection with the Oroville orifice type spillway model. The vortex did not form in this case when a vertical wall extended from the top of the spillway intake to the water surface. However, if a 45° wall sloped from the top of the intake in a downstream direction to the water surface, a vortex would form.

Mr. Campbell quoted Mr. F. F. Escoffier, U. S. Army Engineer District, Mobile, in regard to a peculiar vortex phenomenon which might prove useful. If a small cone extends from the wall of the approach for a bottom outlet, the top of the vortex core will sometimes attach itself to such a projection rather than reaching for the free water surface.

b. Air Entrainment - Criteria for Inception - Measuring Techniques. Mr. Campbell, WES, opened the subject by referring first to the measurement of air entrainment. He described the St. Anthony Falls Laboratory tests using an electrode resistance gap which was described by Lamb and Killem in St. Anthony Falls Technical Paper 2, Series B, 1950. Mr. Campbell also mentioned a design prepared by St. Anthony Falls for prototype measurements. The probe was intended for installation in a spillway chute measuring pier and involved a retractable probe for measuring a variation in resistance in flowing water. It has been suggested more recently that the electrode probe may be fixed on the pier and that the water resistance variation could be measured by a control probe in a vessel supplied by a pitot tube.

c. <u>Techniques for Obtaining Diffusion Coefficients in Open Channels - Turbulence Measurements.</u> Mr. Martin introduced the subject by describing prototype measurements on an irrigation canal. He referred to a paper by J. C. Schuster presented to the Vicksburg Hydraulics Conference, August 18, 1964. The title of the paper was "Canal Discharge Measurements with Radioactive Isotopes." In this activity the Bureau had engaged an expert in the use of radioactive materials. The principle of the process involves the dilution method. The discharge is given by the following equation:

$$Q = \frac{FA}{N} \tag{3}$$

where F is a calibration factor, A is the amount of the tracer, and N is the total count as indicated by the detector. The isotope used was Gold-198.

Mr. Campbell expressed the opinion that the dilution method could probably be conducted by the use of ordinary salt or dye in a much less expensive operation. He believed that radioactive isotopes should only be used for field measurements where it could be proven to be more accurate than conventional injection materials. Dr. Keulegan presented a description of the diffusion theory concerned with the diffusion coefficient in turbulence. Dr. Keulegan wrote the following equations:

$$\frac{\partial c}{\partial t} + U \frac{\partial c}{\partial x} = \frac{\partial^2 c}{\partial x^2} \tag{4}$$

where c is the concentration of salt, dye or other diffusing substance, K is the coefficient of diffusivity and U is the mean velocity. Also:

$$\frac{UH}{K} = C_1 \quad ; \quad \frac{U*H}{K} = C_2 \tag{5}$$

where H is a characteristic dimension of the conveyance such as depth and U* is the shear velocity. The value of C_2 is a function of other hydraulic variables such as cross-sectional shape, character of boundary roughness and velocity distribution.

Mr. Martin closed the discussion by stating that relatively short lived radioactive isotopes must be used in experimental work. He then emphasized that the tests must be conducted quickly because of the rapid decay of the radioactive energy from the isotope.

LUNCH - 12:15 PM TO 1:30 PM

3. d. Model-Prototype Similitude - Transient Pressures on Stilling Basin Walls. Mr. Martin, USBR, opened the discussion by describing the pressure surges against the stilling basin walls of Glendo Dam. The wall shows a lateral movement relative to a section of the wall firmly fixed to the power plant foundation. (A movie of this motion was shown to the Hydraulics Laboratory Techniques Conference held at Denver, 1960.) Subsequently the Bureau installed pressure transducers in the stilling basin model walls of a number of projects being studied. Mr. Campbell said that WES had analyzed some of the Bureau transient pressure tests and found that instantaneous pulses had been much greater than the entering velocity head. A definitive statement based on the Bureau's tests appears in the Engineer Manual 1110-2-1602, pages 34 and 35, Hydraulic Design of Reservoir Outlet Structures. Mr. Theus said that prototype tests of transient pressures could be made at John Day Dam and suggested that Mr. E.B. Pickett, WES, initiate correspondence on this matter. Mr. Martin projected a slide of the Glen Canyon tunnel plug outlet works model indicating the pressures on the intake bell mouth. He said that prototype pressures had recently been made which confirmed the model pressures. Mr. Elder stated that there was confirmation between model and prototype of the lock culvert pressures. No elaboration was given by either Mr. Martin or Mr. Elder on the nature of similitude (frequency and amplitude) of the transient pressures.

TOUR OF DAVID TAYLOR MODEL BASIN

The conferees arrived at the Model Basin at 2:00 PM. They were greeted by the Commanding Officer and Director, Captain J. M. Ballinger, USN. Captain Ballinger presented a very interesting orientation talk with the aid of a three dimensional model of the David Taylor Model Basin. Mr. J. P. Pritchett conducted the tour of the Model Basin.

a. Towing Tank Facilities. The shops were visited where model hulls were fabricated from either, wood or wax, depending upon the problem to be studied. The group toured the main basin building which houses several large towing tanks. The deep water basin is about a half mile long (2780 ft) and is equipped with towing carriages to measure forces on the hull in the three principal directions. The shallow water basin adjoins the deep water basin with a J-shaped turning basin at the end. Parallel with the deep water basin is a high speed towing tank 2970 ft long. The carriage can operate at a maximum speed of 60 knots (101 ft per sec). A demonstration run of the carriage was made for the benefit of the visitors. This would appear to be an excellent facility for testing supports to be used in high velocity chute spillways for prototype tests. It is interesting to note that the carriage rails for the long basin follow the earth's curvature. The midpoint of the rails is approximately 5/8 in. above a chord connecting the ends.

b. Water Tunnels. The David Taylor Model Basin has three well instrumented water tunnels. The largest of these with a 36-in. diameter test section was examined by the group. There is also a circulating water channel which has an open top producing a free water surface test section. This section is 22 ft wide, 60 ft long and 9 ft deep. The maximum test velocity is 10 knots (17 ft per sec). The return flow and propulsion units are deep underneath the test section. It appears that this would be a unique and excellent facility for testing forces on piers at a fairly large scale.

c. Maneuvering and Sea Keeping Facilities. The maneuvering and sea keeping facility is located in a separate large building covering about five acres. They have a circular rotating arm basin which can operate up to 50 knots at a 120 ft radius. This apparatus could probably be used for calibrating high velocity prototype equipment.

The sea keeping facility is 360 ft long. Pneumatic wave machines can produce regular or irregular waves and even a confused sea can be generated. A test run of a model ship was demonstrated. Operating under substantial waves, pitch, roll, heave, surge, sway and yaw can be recorded. The very noisy operating machinery for the pneumatic wave generators in the basement was examined by the conferees.

d. Applied Mathematics Laboratory. This Laboratory is in charge of the eminent mathematician, Dr. H. Polachek, who was not available at the time of the visit. Dr. J. W. Wrench conducted the tour of the laboratory. The three Divisions of interest are: the Mathematical Computations Division, the Data Analysis Division and the Engineering Development Division. The Mathematical Computations Division operates four digital computers which are: two UNIVAC's, an IBM 7090 and a Lark. The Lark is one of the largest digital computers in the nation. Dr. Wrench remarked that one of the advantages of the IBM 7090 was that programs developed by other engineers and mathematicians across the nation can be used directly by them. It appears that liberal use is made of magnetic data tape to store information.

The group was unanimously impressed by the very high quality work being conducted with the obvious liberal funds available to the David Taylor Model Basin.

AGENDA DISCUSSION CONTINUED

The formal session reconvened in the CERC conference room at 8:30 AM, Wednesday, 16 September 1964.

3. e. Measurements of Energy Losses in Spillways. Mr. Campbell introduced the subject with a discussion of analytical studies of previous laboratory and prototype measurements. He prefaced his remarks with a statement that prior to the WES studies only rough empirical criteria were available for design. Reference was made to the USBR observations on Shasta and

Grand Coulee Dams. In the WES studies, use was made of a new concept of energy thickness which was first introduced by Weighardt in Germany. The computation is discussed in Advanced Mechanics of Fluids, edited by H. Rouse, page 311. The equation for head loss in an overflow spillway can be written:

$$H_L = \frac{\delta_3 \ U^3}{2 \ gq} \tag{6}$$

where U is the velocity above the turbulent boundary layer and q is the discharge per ft of width. The energy thickness can be expressed as

$$\delta_3 = \int_o^\delta \frac{u}{U} \left(1 - \frac{u^2}{U^2} \right) dy \tag{7}$$

Where δ is the thickness of the turbulent boundary and u is the velocity at a distance y from the solid boundary. Therefore, when the vertical velocity is known, the above equation can be integrated numerically to obtain the energy thickness. The studies made by Bauer at Iowa were used to deduce the following relationship:

$$\delta_3 = 0.22 \ \delta \tag{8}$$

Bauer also plotted his data on a graph of δ/L vs L/k. Bauer's graph was revised by WES with the addition of new data on the critical point where the turbulent boundary layer reaches the surface. Therefore the designer can estimate the boundary layer thickness data from a graph, determine δ_3 from equation (6) and solve for head loss by equation (8). This method has been included in the OCE Engineer Manual 1110-2-1603 soon to be published. It has also been presented to ASCE for publication.

More field observations are needed to establish a firm relationship on the Bauer graph. Photographs of the beginning of white water at Detroit Dam and plaster casts of the roughness have been furnished by the NPD Hydraulic Laboratory. Mr. Douma expressed an interest in future tests on the Detroit spillway. Mr. Campbell believed that instruments could be held in the flow a short distance downstream from the crest without danger of damage to the supporting elements or the carriage.

4. MATHEMATICAL APPROACH TECHNIQUES

4. a. High Speed Computer Oriented Data Acquisition. Mr. Martin opened the discussion. The USBR is investigating equipment to digitize data directly from experimental observations. This equipment will supplement the new Honeywell H-800/200 computer now being installed. It was indicated that high speed computers have been used in USBR for data analysis on the following problems as examples: canal seepage measurement analyses, computations for fall velocity of sediment, integration of forces on vertical stilling wells, laboratory pressures, roughness computations and

the relaxation of flow nets. A report on flow nets has been completed (reference) HYD-500 "Use of an Electronic Computer to Obtain Flow Nets for a Channel with 90° Into-the-Flow Offsets," by H. T. Falvey. A chart was projected on the screen which shows the flow of technical data from pressure pickups through the final analysis. Mr. Dale, TVA, said that their organization used magnetic data tape in combination with an oscillogram chart to monitor the signal response. Mr. Savage, CERC, noted that they have a contract with Scripps Institution of Oceanography under which a new method of recording wave data is being developed. The process involves digitizing the information in the field.

b. New Analytical Techniques with High Speed Computers - Flip Buckets and Power Plant Transients. Mr. Campbell introduced the subject with a discussion of the theory of flip bucket trajectories. The WES studies indicate that a simple trajectory computation does not fit either the model or prototype data. Drs. J. S. McNown and Y. S. Yu were engaged to pursue a conformal mapping study originally suggested by Shields of Norway before the age of electronic computers. By modifications of the approach Dr. Yu was able to devise a satisfactory program. However, the method does not yield results for the hydraulic variables in the range of design experience. (Subsequent to the conference, Dr. McNown demonstrated a successful solution by the integral equation method.) At about the time when it became apparent that the modified Shields' method could not be used for this particular problem, Dr. J. J. Cassidy had completed a doctoral dissertation at the State University of Iowa on a specialized relaxation method. Therefore, Dr. Cassidy, now of the University of Missouri, was engaged to examine the flip bucket problem. In general, his scheme involves transferring the two dimensional flow net from the real plane to a logarithmic hodograph plane. The relaxation process is performed in this plane. Transferring back to the real plane, certain adjustments of water surface and other hydraulic variables are made, and the flow net is transferred into the logarithmic hodograph plane again for further relaxation procedures. No report has yet been received from Dr. Cassidy on his results.

The Garrison and Oahe power plant transients tests had previously been reported at the Third Conference in Denver. Mr. Campbell described the process of handling the field observations. The data points were transferred from the oscillograms to punched paper tape by means of a Gerber digitizer. The paper tape data were then transferred to cards on an IBM card punch machine. These card decks were sent to the Omaha District where application of the calibrations were made on an IBM 650. The Omaha District card decks were then sent to the contractor, MIT, for solution of the 40 odd simultaneous equations. Mr. Douma asked when the reports would be completed on these studies. Mr. Campbell explained that the WES responsibility was to report on the field measurements only. A symposium is scheduled for the ASCE Mobile Conference, March 8-12, 1965. Several papers will be presented in this symposium which will cover the entire operation. It is anticipated that the papers will be presented to ASCE for publication as a symposium.

c. Analog Simulations - Surge Tank Oscillations. Mr. Martin introduced the topic by describing a pipe line project extending 125 miles south from Amarillo, Texas. At intervals along the pipe line, weir stands are being installed to control the flow. The USBR laboratory built a distorted pipe model to simulate the prototype including the weir stands. A portion of this study is concerned with checking design information obtained from a comprehensive numerical analysis conducted with an electronic digital computer. When the project is completed, observations will be made in the prototype.

Mr. Campbell mentioned a paper on surge tank oscillations studied by an analog computer. The paper was presented by Prof. V. C. Rideout at the ASCE Hydraulics Division Conference, Madison, Wisconsin, August 23, 1956. Independent variables such as penstock length and diameter, surge tank diameter and friction losses could be easily modified. The hydraulics of the surge was measured for various turbine gate closure times. MIT used a similar analog technique and exploratory studies for the Garrison and Oahe power plant transients tests. Mr. Dale said that an electrical analog had been used for a similar problem at TVA.

5. SEDIMENTATION AND ROCK MOVEMENT

5. a. Laboratory Studies of Riprap Stability. Mr. Murphy, WES, described a model study of the Little Sioux River drop structure which will be submerged at high flow. Photographs were passed around to show that the riprap back of the training walls was washed out in both model and prototype. The WES laboratory has also made studies of flow over a rock dike. Small pressure transducers were positioned on the stone at the bottom of the first and second layer. The test record showed that very small pressure fluctuations were evident under the top layer and no pulsations detected under the second layer. It was estimated that the pressures under the top layer were only half enough to displace the rock. They estimated that 40% or more of the critical size would be needed for stability. Mr. Douma mentioned that the Missouri River Division and Omaha District have made a test section of Filter-X materials.

b. Interchange of Water and Sediment at a Coarse Gravel Interface. Mr. Martin said that their interest with this subject involves the spawning of fish in the bottom of canals. He explained that the fish lay eggs on the coarse gravel which lines the canals. They are seeking to obtain velocity of 4 ft per hr through the gravel to maintain oxygen in the water. The USBR has used dye travel time and the salt velocity method for laboratory studies. Dr. Keulegan suggested that the electro-kinetic potential principal could be used to measure low velocities. Mr. Savage of CERC said that the hydrodynamics laboratory at MIT has used thermistors to measure velocities. CERC has issued a report entitled: "A Thermistor Probe for Measuring Particle Orbital Speed in Water Waves," TM No. 3. The report is based on work conducted at MIT.

c. Experience Data on Rock Movement as a Function of Boundary Velocity. Mr. Murphy described channel studies at WES where rock movement was noted. Mr. Martin referred to the riprap failure at Grand Coulee Dam and the field study methods used to determine minimum size stone required for bank stabilization. Mr. Douma expressed an opinion that a more thorough study should be conducted on this subject.

BREAK - 10:30 AM - 10:45 AM

6. INSTRUMENTATION

6. a. Techniques for Amplifying Extremely Small Hydraulic Signals. Mr. Martin said that the Bureau had been using a pressure transducer connected to a Preston tube to measure wall shear in the model. This technique is described in Report No. HYD-526, "Progress Report 1 - Boundary Shear Distribution Around a Curve in a Laboratory Canal," June 24, 1964. Mr. Duke described a differential pressure transducer made by the Foxboro Company which will measure a head difference of 2 inches of water. The cost of this apparatus is about $600.00 each including the necessary D.C. power supply. Mr. Williams of CERC mentioned a Westinghouse flowmeter. Their contact with Westinghouse is through a Mr. Bradey in Washington. The Scripps Institute is supposed to have purchased a later model of the Westinghouse equipment.

b. Advances in Methods of Prototype Discharge Measurements - Acoustic Methods. Mr. Duke, WES, described the acoustic method using rods on either side of the Sutton rectangular intake. He also described the point source proposed for use at Summersville Dam in the Huntington District. A contract is being drawn with the Westinghouse Underseas Division to build the point source equipment. Testing of the apparatus is to be conducted at Oahe Dam in the latter part of October 1964. Mr. Williams, CERC, mentioned that the USGS had a contract with Raytheon for an acoustic flowmeter to be used in natural stream channels.

c. Turbine Discharge Measurements at Intake Gate Locations. Mr. Price, TVA, described the measurements which were made on the power intakes at the Wilson Dam. The Ott meters were fixed on a frame work which spanned the cross section of the intake. The signals from the meters were read out electronically. Mr. Theus, NPD, described similar tests made on power plants in their Division. Neyrpic current meters were mounted on beams in the intake. These cosine meters are claimed to be accurate to a 30^{o} angle to the current direction. Mr. Theus states that the Bureau of Standards calibrations did not check with those of the manufacturer for high velocities. The meters were also rated by the DTMB, and Convair, both of which ratings agree with each other. The NPD Laboratory can now calibrate velocity measuring equipment up to $12\frac{1}{2}$ ft per sec in their own towing tank. Mr. Murphy mentioned the work which has been done by the British at the East Kilbride Laboratory. Extensive discussion ensued regarding the accuracy of velocity measuring methods.

d. Recent Advances in Pressure Transducers and/or Velocity Measuring Equipment. The USBR yielded the introduction of the subject to the DTMB. Mr. Brownell discussed semi conductors made of silicon which are sensitive to strain and the thermistor material which is sensitive to temperature changes. Mr. Williams said that there are strain sensitive bars available on the market. Mr. Duke mentioned a 1/8 in. diameter pressure transducer being used on Bell helicopters. The equipment was developed by the Battel Research Institute in Columbus, Ohio.

e. Techniques for Measuring Low Amplitude Pressures Varying from Positive to Negative. Mr. Williams mentioned a soleon cell which was developed by the University of Texas Defense Research Laboratory under contract with the Navy Oceanographic Office at Buzzards Bay. A report has been prepared entitled: "Practical Aspects of Bottom Pressure Studies," by G. N. Ellis and J. L. Collins, 29 June 1964. The operation of the cell involves pumping iodine pass the electrodes. Mr. Martin mentioned midget meters with plastic propellers made by Armstrong Whitworth. Mr. Elder described a low velocity meter which measures both velocity magnitude and direction. This apparatus is called DWICA 1, with a later model called DWICA 2. These instruments were developed by AEC for use in studying bottom ocean currents. The instruments make use of radioactive isotopes. The isotope is injected from a frame resting on the bottom. Radioactivity pickups are placed in a circle concentric with the injection point. The TVA is interested in this equipment for measuring velocities and direction of density current flow.

LUNCH - 12:20 PM - 1:10 PM

TOUR OF COASTAL ENGINEERING RESEARCH CENTER LABORATORY

Col. F. O. Diercks presented an orientation talk to the conference prior to the tour of the laboratory. He explained the organization and missions of the CERC. He then introduced Mr. R. P. Savage who conducted the tour of the laboratory.

The operation of the large indoor wave tank was demonstrated. This is a flume 85 ft long by 15 ft wide. The wave machine is operated by a $7\frac{1}{2}$ hp motor and has a 45° scoop type leaf with a vertical attachment which can be used. The sloping beach at the far end was set at an angle so that runup of 45° incident waves could be studied.

The two 18 in. wide indoor wave tanks were demonstrated. Dr. C. J. Galvin, Jr., who recently received his doctorate at MIT, was conducting a study on the basic theory of breaking waves in one of the flumes. He was concerned with waves breaking on a sloping beach. In the other small tank Mr. R. H. Multer, recently of WES, was conducting a study of secondary waves recently found to be important in wave tank studies. Dr. Keulegan stayed an extra day in Washington to consult on the problem at Mr. Multer's request.

A brief demonstration was made of the ripple tank in which wave refraction, diffraction, and reflection can be shown.

The large outdoor wave tank is 635 ft long, 20 ft deep, and 15 ft wide. The wave machine is driven by an 800 hp variable drive D.C. motor which can generate waves 6 ft high. At the time of the tour, the Navy Bureau of Yards and Docks barge loading device was demonstrated. This is an unique device in which the hoist mechanism has a sensing cable attached to the rising and falling barge. The hoist lead causes the load to follow the rise and fall of the barge. By gradually closing the vertical distance contact of the load with the barge is made.

The shore processes test basin which is 300 ft by 150 ft was inspected. The movement of sand along the shore caused by obliquely approaching waves was demonstrated.

The Instrumentation Laboratory was demonstrated by Mr. Leo C. Williams. The CERC manufactures several types of wave gages. A wave gage employing parallel resistance leads is used for salt water. A series type gage with step resistance is used for fresh water. The CERC Laboratory has equipment to record wave heights on magnetic tape and to interpret them by spectral analysis.

AGENDA DISCUSSION CONTINUED

6. f. Instrumentation Developments Since 1960. Mr. Dale, TVA, introduced the subject. He described a velocity meter manufactured by Thermosystems Corporation, Minneapolis. The element is of platinum with gold coating on the ends. The sensing portion of the wire has a quartz coating. This is a hot-wire anemometer type of instrument. The cost of the meter with 5 probes is $3500. Mr. Dale expressed a favorable impression of the instrument because it was equipped with solid state components.

7. MISCELLANEOUS PROBLEMS

a. Dynamic Behavior of Lock Valves. Mr. Elder, TVA, discussed the model studies on reverse tainter culvert valve for both Wheeler and Melton Hill Locks. Prototype observations have also been made. Conventional bulkhead slots downstream from the tainter valves are used. The elevation of the seal in the bulkhead well was varied and the mass oscillation of water studied. TVA observed a phenomenon which they called random slamming. Pressure transducers have been installed in the prototype. It was stated that the pressure fluctuations in the prototype agreed with those observed in the model. Mr. Dale stated that studies have been made on this problem with an analog computer in which the damping was varied.

b. Studies of Flow Stratification in Reservoirs, Channels and Porous Media. The Agenda Item 7d which concerns measuring low velocities in porous media was combined with this item. Mr. Martin opened the discussion. The Bureau is interested in studying displacement of salt water by fresh water in irrigated soils. A model has been constructed with parallel drains under the surface. By means of a dye called Patent Blue, observations were made to determine whether fresh water placed on top would force the saline water into the drains. Displacement of saline water from aquifiers into drains was measured by chemical laboratory techniques for determining concentration of KCl, the tracer used in the studies.

c. Instrumentation and Measurement Techniques for the Study of Density Flows. Mr. Elder opened the discussion and noted that part of his information had been discussed previously under Item 6e. In general the TVA is interested in the cold layers in the reservoirs supplied from fresh water flows and the heat layers caused by waste water from thermoelectric plants. They are particularly concerned with the vertical location of intakes from reservoirs in order to select the temperature of the outflow. The TVA is interested in development of recreation fishing and especially cold water fishing which is becoming popular in the region. Salt measurements are made of the variation of density and temperature with depth in the reservoir. Temperatures are measured with a thermistor. Mr. Theus, NPD Laboratory, advised that the Walla Walla District was making studies of reservoir density layers at Dworshak. Mr. Douma noted that the Lake Survey was using equipment to measure the velocity and direction of flow. Mr. Duke stated that this equipment had been developed and manufactured at WES.

e. Techniques of Measuring Oxygen Content of Water in a Gravel Channel Bed. To measure dissolved oxygen content in deep reservoirs and spawning gravels, USBR has been testing an oxygen analyzer which operates on the galvanic cell principle. A probe consisting of a ring-shaped lead anode surrounding a silver cathode is covered with a Teflon membrane containing a small amount of electrolyte which is held against the lead-silver probe with an O-ring. Oxygen permeates the gas-permeable Teflon membrane and produces a current by catalytic action which is indicated on the sensor. Failure of the seals on the small pump which circulates the water across the membrane has been experienced at greater reservoir depths.

f. Techniques for Detecting and Measuring Seepage from Earth and Lined Channels. USBR is experimenting with electrical logging equipment of the general type which has been successfully used in logging oil wells, to delineate canal seepage areas which are most in need of seepage control measures. This method involves the measurement of resistivity of soil in seepage areas and the measurement of small voltages developed by the flow of water through the canal soil.

g. River Heat Budget Studies. Mr. Elder discussed this subject. The purpose of the study is to gather sufficient information so that warm layers of water will not be created at power intakes. This is a theoretical study but two sets of field observations have been made at John Sevier Steam Plant in Tennessee and the Shawville Steam Plant in Pennsylvania. Consideration is given to the solar radiation, the surface temperature, evaporation, rainfall and air temperature. It was noted that at 96°F the river can be sterilized of all aquatic life.

CRITIQUE

Mr. Douma noted that previous conferences have been held at Vicksburg in 1956, on the West Coast in 1957, and at the Bureau of Reclamation at Denver in 1960. A number of the conferees expressed enthusiasm about the value of these conferences and it was decided they should be continued. A discussion as to length of time between meetings led to the conclusion to hold them every two years. It was felt that, in view of the rapid advancements being made in instrumentation, three years was too long a lapse. The next meeting would therefore be planned for 1966 and Mr. Douma suggested September or October of that year. Mr. Douma asked whether TVA would be willing to be host to the next conference. Mr. Elder said that TVA would welcome the chance to be host to the group. Mr. Douma closed the conference with an expression of appreciation to the hospitality of Col. Diercks and his staff at the Coastal Engineering Research Center.

F. B. CAMPBELL, WES
Recorder

FOURTH INTERAGENCY CONFERENCE ON
HYDRAULICS LABORATORY TECHNIQUES AND INSTRUMENTATION

U. S. ARMY COASTAL ENGINEERING RESEARCH CENTER
WASHINGTON, D. C.

15-16 SEPTEMBER 1964

LIST OF ATTENDEES

U. S. Army Engineers

Office, Chief of Engineers
Jacob H. Douma, Presiding

Coastal Engineering Research Center, Hosts
Col. F. O. Diercks, Director
R. P. Savage, Research Division
John C. Fairchild, Research Division
Leo C. Williams, Research Division

Waterways Experiment Station
F. B. Campbell, Recorder, Hydraulics Division
G. H. Keulegan, Hydraulics Division
T. E. Murphy, Hydraulics Division
L. M. Duke, Instrumentation Branch

North Pacific Division Hydraulic Laboratory
Harry P. Theus
Alvin J. Chanda
William O. Dement
G. Robert Grim

U. S. Bureau of Reclamation
H. M. Martin

U. S. Navy - David Taylor Model Basin
W. F. Brownell

Tennessee Valley Authority - Engineering Laboratory
Rex A. Elder
James A. Dale
James T. Price

Present Part Time

U. S. Army Engineers - Coastal Engineering Research Center
Joseph M. Caldwell
Roger H. Multer

FOURTH INTERAGENCY CONFERENCE ON HYDRAULICS LABORATORY TECHNIQUES AND INSTRUMENTATION

AGENDA

Tuesday, 15 September

8:10-8:15 A	Welcome by Col. F. O. Diercks, Director, CERC
8:15-9:15	Wave Action Facilities and Techniques
9:15-10:15	Closed Conduit Flow Measurements
10:15-10:30	Break
10:30-12:00	Free Water Surface Phenomena Measurements
12:00-1:00 P	Lunch
1:00-1:45	General Discussion
1:45-2:00	En Route DTMB
2:00-4:00	Inspection of DTMB

Wednesday, 16 September

8:15-9:15 A	Mathematical Approach Techniques
9:15-10:15	Sedimentation and Rock Movement
10:15-10:30	Break
10:30-12:00	Instrumentation
12:00-1:00 P	Lunch
1:00-2:30	Inspection of CERC
2:30-4:00	Miscellaneous Problems
4:00-4:30	Critique - Suggestions for Future Conferences

DISCUSSION TOPICS

1. Wave Action Facilities and Techniques

a.	Techniques for measuring and controlling bore waves in canals - wave analyzers	USBR
b.	Wave Making Facilities and Techniques	DTMB & CERC*
c.	Methods of Reproducing Tsunamis	NPDL & WES*

2. Closed Conduit Flow Measurements

a.	Cavitation measurements	USBR & DTMB*
b.	Techniques for measuring wall roughness and boundary shear-field measurements	WES & DTMB*
c.	Techniques for measuring boundary layer effects in models	USBR & WES*

3. Free Water Surface Phenomena Measurements

a.	Free surface vortex-model and prototype similitude	USBR & WES*
b.	Air Entrainment - criteria for inception - measuring techniques	WES & USBR*
c.	Techniques for obtaining diffusion coefficients in open channels - turbulence measurements	USBR
d.	Model-prototype similitude - transient pressures on stilling basin walls	USBR
e.	Measurements of Energy Losses in Spillways	WES

4. Mathematical Approach Techniques

a.	High speed computer oriented data acquisition	USBR
b.	New analytical techniques with high speed computers - flip buckets and power plant transients	WES & USBR*
c.	Analogue Simulations - Surge Tank Oscillations	USBR & WES*

*Organization listed first will introduce topic

5. Sedimentation and Rock Movement

a.	Laboratory Studies of Riprap stability	WES
b.	Interchange of water and sediment at a coarse gravel interface	USBR
c.	Experience data on rock movement as a function of boundary velocity	WES

6. Instrumentation

a.	Techniques for amplifying extremely small hydraulic signals	USBR
b.	Advances in methods of prototype discharge measurements - acoustic methods	WES & USBR*
c.	Turbine discharge measurements at intake gate locations	TVA
d.	Recent advances in pressure transducers and/or velocity measuring equipment	USBR, DTMB, & WES*
e.	Techniques for measuring low amplitude pressures varying from positive to negative	WES & USBR*
f.	Instrumentation developments since 1960	TVA

7. Miscellaneous Problems

a.	Dynamic behavior of lock valves	TVA
b.	Studies of flow stratification in reservoirs, channels and porous media	USBR
c.	Instrumentation and measurement techniques for the study of density flows	TVA
d.	Flow measuring techniques in porous media - low velocities - model techniques	USBR
e.	Techniques of measuring oxygen content of water in a gravel channel bed	USBR
f.	Techniques for detecting and measuring seepage from earth and lined channels	USBR
g.	River heat budget studies	TVA

WAVE-MAKING FACILITIES AND TECHNIQUES

by

Joseph M. Caldwell, CERC

1. Wave generators usually designed for following:

   (a) Deep-water or shallow-water waves.

   (b) Simple wave trains or complex wave trains.

   (c) Small-scale waves or large-scale waves (compared to prototype).

   (d) Constant water depth or varying water depth.

Possibly the "funds available" factor should also be introduced as it has considerable influence on the final selection.

2. Generally, the wave work at CERC (and also largely at WES) has been oriented toward shallow-water waves; so the presentation will be mostly geared to this type of generation. Of course, a wave train can be generated as in deep water and then be converted to a shallow-water train by the hydrography of the channel or basin, but this presentation, for the sake of time, will be restricted generally to waves generated as shallow-water waves.

3. Actually, if we exclude the generation of waves by blowing wind over the water surface, we see that the generation is resolved into: (1) the selection of the shape and motion of the body (or generator) that displaces the water in such a way as to generate the desired wave; and (2) the selection of a driving mechanism to impart the required motion to the generator.

4. The most intensive study of wave generators at CERC came about with the design of the generators for our Shore Processes Test Basin and our prototype Wave Tank. The following methods of generation were considered and discarded for the reasons given in each case:

   (a) Simple flap-type generator.

      (1) Did not work well over a wide range of depth. Required excessive displacement of top to give required displacement with water low on flap. Probably require pit (not practical on SPTB).

(b) Differential motion bulkhead.

(1) The mechanism was too complicated (and expensive) when applied to the wide range of depths, heights, and periods needed.

(2) Not generally suitable to a machine which must be shifted to different locations in a basin.

(c) Blower generated.

(1) No design was found which operated satisfactorily over a wide range of depths.

(2) The horsepower requirements quickly became excessive for waves of appreciable size. To generate a wave with translated power of 100 hp., a total blower capacity of some 2,000 or 3,000 hp. was indicated.

(3) The noise of blowers operation is a problem in many areas.

(d) Plunger-type generator. (Triangular or rectangular.)

(1) Not readily adaptable for operation over a wide range of depths. Would require a generator pit of considerable depth for many conditions. (Pit not feasible in Shore Processes Test Basin.)

5. The selection, then, came down to a vertical bulkhead generator. This type, by virture of its motion of horizontal displacement was effective in variable depths of water and did not require a pit for operation. This simple generator was adapted for use in the SPTB.

6. Though the use of the vertical bulkhead was indicated for the PWT in our tests, we were somewhat concerned by the fact that in its simplest form it required a 17-foot stroke to generate our design wave of 6-foot height at a 16-sec. period in 15 feet of water. We tested methods of overcoming this by using a widened section at the generator. This will act to cut down the required stroke but it was necessary to quadruple the width to cut the stroke in half. This relation, of course, is governed by the energy relations indicated by Green's Law.

$$\frac{h_d}{h_i} = \frac{B_i^{\frac{1}{2}} \; D_i^{\frac{1}{4}}}{B_e^{\frac{1}{2}} \; D_e^{\frac{1}{4}}}$$

which give the following relationships:

For a constant depth D,

$$h_e B_e^{\frac{1}{2}} = h_i B_i^{\frac{1}{2}}$$

recognizing that h_e would be twice h_i

$$(2)\ (B_e^{\frac{1}{2}}) = (1)\ (B_i)^{\frac{1}{2}}$$

squaring

$$4\ B_e = B_i$$

This widened section and elongated generator were found to be even more expensive to construct (even with the stroke reduced to $8\frac{1}{2}$ feet) than the simpler generator. Also, there were pronounced undesirable transverse oscillations set up in the wider generator basin at certain periods. Splitter walls were required to overcome these oscillations.

7. Thus, the decision was made to use a simple bulkhead generator of the same face X-section as the tank. (You will note that all of our generators have been constructed to operate on this principle.)

8. One interesting facet of the design for the large tank was the handling of the area behind the generator bulkhead. We recognized that the rear wave could be allowed to dissipate on a rear beach or absorber, but this would require that the tank be lengthened as much as 100 feet or more. Instead, it was found possible to have the rear area act more as a surge tank. This not only saved more than a hundred feet of tank construction, but it also enabled the rear energy to be stored in the rising surge and then used to assist in pushing the bulkhead forward on the forward stroke. This reduced by about one-half the peak power requirement, the average power requirement, and the maximum thrust on the bulkhead. As constructed, these values are 500 hp., 150 hp., and 35 tons. Thus these savings are meaningful in this case whereas they might be insignificant in a smaller tank.

Flexibility in Drive

9. It is desirable to have flexibility in both stroke and period. The goal would, of course, be to have the apparatus generate any desired wave train including a "confused" sea. The speed is more easily varied than the stroke and all our generators have variable speed drives. The two large tanks have the most flexible speed control, as they can be

varied by simply turning a rheostat. Our smaller tanks have vari-drive motors. At this time, however, we have out for bids a hydraulic piston-type of drive that will permit programming an irregular set of waves over a wide spectrum. We hope to have this installed within a few months. (It is somewhat similar to the one at MIT.)

10. In closing, may I say that we do not promote our wave generators as being the best available. They best-fitted our particular needs and budget at the time they were constructed. We recommend that each laboratory consider its own particular needs (and budget) in its design of wave generators.

FACTORS IN DESIGN

a. Deep or shallow water waves

b. Simple or complex wave train

c. Smale scale or large scale waves

d. Constant or varying depths

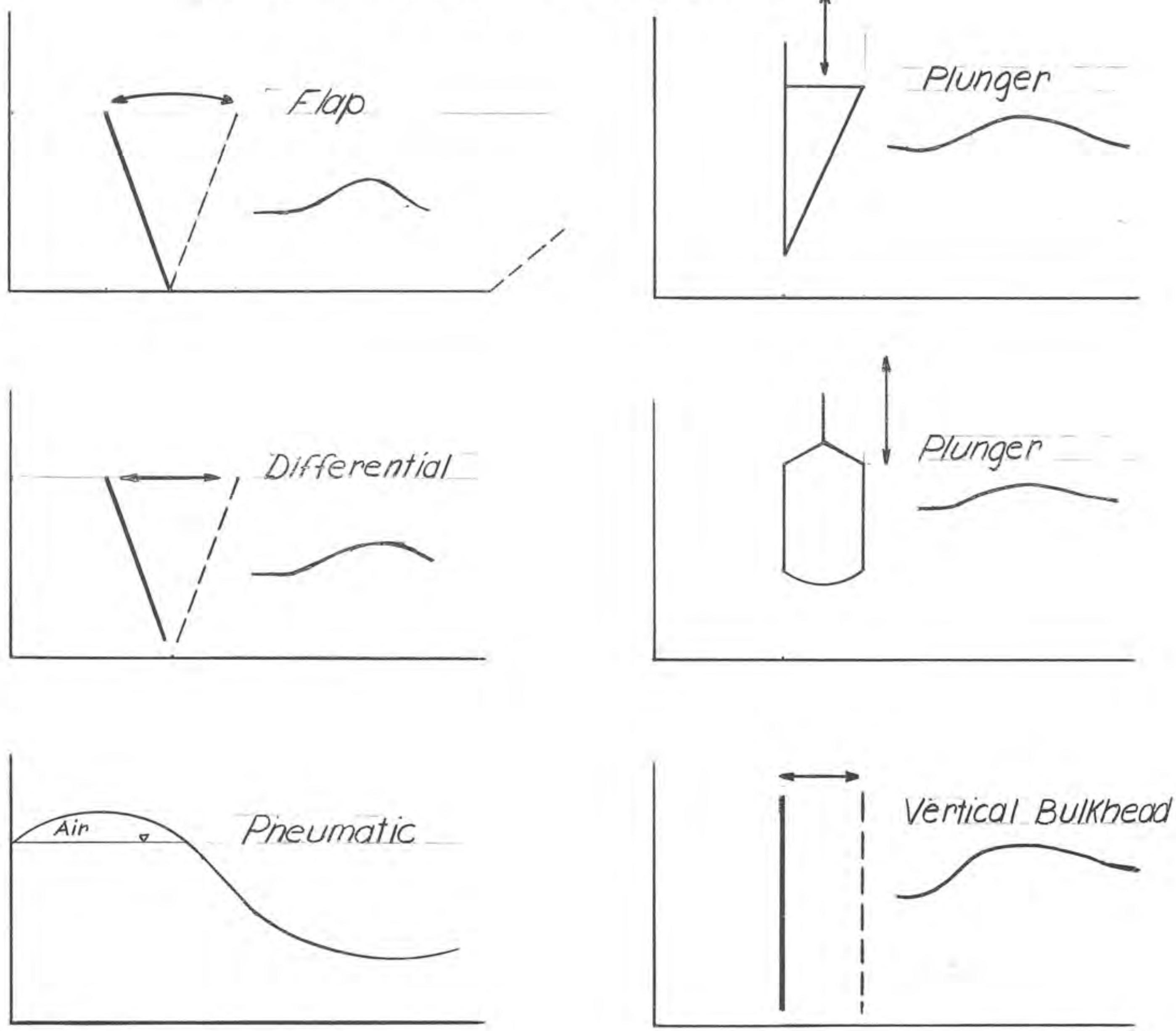
e. Mobility

f. (Budget)

SELECTIONS

1. Method of generation
2. Method of driving

TYPES OF WAVE GENERATORS



CERC WAVE GENERATOR