H. M. Martin, Code 293

Bureau of Reclamation, Corps of Engineers, Tennessee Valley Authority,
and U. S. Navy David Taylor Model Basin
August 9 and 10, 1960

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NOTES

OF

MEETING ON HYDRAULIC LABORATORY TECHNIQUES

3rd Conference

Bureau of Reclamation
Denver, Colorado

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MEETING ON LABORATORY TECHNIQUES
August 9-10, 1960
Bureau of Reclamation
Denver Federal Center

Corps of Engineers

Office of Chief of Engineers

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Colonel Edmund H. Lang, Director
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Mr. George B. Fenwick, Chief, Rivers and Harbors Branch
Mr. Frank B. Campbell, Chief, Hydraulic Analysis Branch
Mr. Thomas E. Murphy, Chief, Structures Section, Hydrodynamics Branch

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Mr. Martin E. Nelson, Chief, Hydraulic Laboratory Branch

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Mr. A. P. Gildea, Chief, Hydraulic Section
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Mr. James A. Dale, Instrumentation Specialist
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Thomas J. Rhone, Hydraulic Research Engineer
William P. Simmons, Hydraulic Research Engineer
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Agenda for Meeting on
Hydraulic Laboratory Techniques
August 9-10, 1960
In Cooperation with
Corps of Engineers
Tennessee Valley Authority
U. S. Navy David Taylor Model Basin

Tuesday, August 9, 1960

8 to 9 a.m. Orientation

Welcome--Mr. Grant Bloodgood, Assistant Commissioner and Chief Engineer

Outline of Activities of Bureau of Reclamation Engineering Laboratories--Mr. W. H. Price, Chief Research Engineer

Recess--15 minutes

9:15 to 11:30 a.m. Tour of Bureau Engineering Laboratories

Lunch

Discussion Session Chairman--H. M. Martin

12:30 to 2 p.m. Discussion--Hydraulic structures

Vortex flow and model-prototype similitude

Hydraulic measurements of effect of high velocity flow at surface irregularities

Recess--15 minutes

2:15 to 3:45 p.m. Discussion--Hydraulic structures

Protective-material studies in model and prototype--Structures, conveyances, shorelines, riprap, other means

Hydraulics of large conveyances--Basic fluid mechanics concepts--Instrumentation

Wednesday, August 10, 1960

8 to 9:30 a.m. Discussion--Hydraulic equipment and closed conduits

Application of air testing

Energy dissipation in closed conduits--Laboratory studies of sudden enlargements; other

Similitude problems of aeration in closed conduits

Recess--15 minutes

9:45 to 11:30 a.m. Discussion--Sediment research

Materials and measurements in movable bed hydraulic model and prototype studies

Use of radioisotopes in sedimentation studies

Representing sediment transport in intermittent streams

Lunch

12:30 to 2 p.m. Discussion--Instrumentation Analogs and Data Processing

Instrumentation for prototype measurements

Ultrasonic devices; hydrophones

Methods of recording and processing data

Recess--15 minutes

2:15 to 3:45 p.m. Discussion--Special tests and Summary

Special tests performed by participating laboratories--Wave studies; seepage and seepage control

Summary

THESE AGENDA ARE TENTATIVE AND MAY BE MODIFIED ACCORDING TO THE INTERESTS OF THOSE ATTENDING.

INTRODUCTION

Representatives from the Hydraulic Laboratories of the Corps of Engineers (U. S. Army), Tennessee Valley Authority, David Taylor Model Basin (U. S. Navy), and the Bureau of Reclamation met at the Denver Federal Center for discussions of methods of improving hydraulic investigations and data analyses through an exchange of ideas and information. The meeting, arranged by correspondence through the interested agencies, was hosted by the Bureau and was the third of a series started by the Corps of Engineers in 1956.

SUMMARY

The conference was considered timely and beneficial by the participants. Although the research activities of the four laboratories apply to the requirements of the respective organizations, techniques and equipment for measuring hydraulic phenomena are similar. Freely exchanged ideas by the participants from experiences stimulated the discussions and will lead to new thoughts, better testing procedures, equipment, and instrumentation.

NOTES

Meeting on Hydraulic Laboratory Techniques
August 9-10, 1960

The meeting was called to order by Walter H. Price, Chief Research Engineer, at 8:15 a.m. on Tuesday, August 9, 1960. Mr. Price introduced Grant Bloodgood, Assistant Commissioner and Chief Engineer of the Bureau of Reclamation, who welcomed the participants with the following remarks:

> Gentlemen, welcome to the Engineering Center of the Bureau of Reclamation.
>
> We are pleased to welcome such an outstanding group of hydraulic research engineers as yourselves. Among your number, you represent most of the top Federal organizations working in this field. I join Mr. Price and his staff in believing that this meeting will be highly beneficial to all our organizations in the exchange of ideas and information on hydraulic laboratory and testing techniques.
>
> As you know, the value of meetings such as this was recognized in 1956, when hydraulic research engineers of the various Corps of Engineers laboratories and offices were called into Vicksburg

to discuss technical practices in a variety of hydraulic investigations. Although the Bureau was unable to participate at that time, it was aware of the success of that gathering and subsequent meetings at the Corps laboratories at Los Angeles, San Francisco, and Bonneville Dam, Oregon, through the reported results.

It has been 3 years since the most recent meeting of this type, and we are happy that the Bureau is able to act as host at this time.

We are pleased that the Tennessee Valley Authority and the David Taylor Model Basin have added their experience and talent to this series by sending representatives. I view this growth of participation as a compliment to the Vicksburg Laboratories.

A few words about the work of the Bureau might now be appropriate for those of you from the east and south who may not be so familiar with Reclamation. Our activity is confined to the 18 Western States, including Alaska. In these states, we design, build, and operate the water storage dams and distribution systems that bring irrigation to the land. When we build a storage dam, we create the opportunity for hydroelectric power production--so we develop these water drops on some projects by constructing powerplants. We also include flood control and river regulation in our projects where feasible. Recreation is another dividend of our work.

To date, the Bureau of Reclamation has built or has under construction a total of 295 storage and diversion dams; 25,000 miles of canals and laterals and 47 powerplants, plus tunnels, transmission lines, pumping plants, and other structures. These are the engineering features that lie behind the end product of 1 billion dollars worth of crops grown on Reclamation farms last year and 78 million dollars in electric energy sales by Reclamation power systems.

You will soon tour the Engineering Laboratories, and I wish to say a few things about them. The laboratories are an important tool of our engineering planning and design. From these laboratories, our project planners and designers get answers to many of their questions on the quality of water for irrigation purposes, the types and uses of soils for agricultural and engineering purposes, the strength and other properties of various concrete mixes, the durability of paints, and numerous other problems requiring laboratory techniques and methods, as well as those involving your field of hydraulics.

Because of the growing general concern for the nation's water supplies and their technical aspects of special interest to you as engineers, I will mention two investigations of our laboratories into this important matter. One of these is the investigation of means for reducing reservoir evaporation. Some 11 million acre-feet of water are evaporated from our reservoirs each year. If only a portion of this could be saved by some method, it would be very beneficial to our western economy. Reduction in evaporation is accomplished by spreading a chemical monolayer on the surface of the reservoir. It has been demonstrated that evaporation can be reduced by as much as 50 percent with these monolayers. We will show you how this chemical is applied on your tour of the laboratories.

I am sure that many of you are aware of the studies of the Office of Saline Water to demineralize sea and brackish water. Our laboratories here in Denver have been collaborating with that office in studies of selective membranes for demineralization of brackish waters. We have also been cooperating with the Office of Saline Water in preparation of plans and specifications for a 250,000-gallon-per-day demineralizing plant using selective membranes which will be constructed at Webster, South Dakota. This method of demineralizing water will be on display in the laboratories for you to view on your tour.

There is one piece of equipment in our building that Mr. Martin seems not to have been able to use in his hydraulic studies. I am sure that he regrets this, but we want to demonstrate it to you anyway. We have one of the largest Universal testing machines in the world here in our laboratories. This morning at 11:30, at the end of your tour, you will witness the breaking of an 18- by 36-inch concrete cylinder in this machine.

Mr. Price will outline the activities of the Bureau Laboratories in more detail this morning. I note that the agenda for your meeting is very full of a number of topics you have chosen as being timely and important in the advancement of hydraulic techniques. I understand that several of you have suggested a number of additional topics related to design practice which fall outside the scope of this 2-day meeting. I would like to invite those of you who have the time to discuss those topics with our design and laboratory engineers on Thursday or later.

Thank you. My best wishes for a successful meeting.

Activities of the Reclamation Engineering Laboratories and their subdivision into Chemical Engineering, Concrete, Earth, Hydraulic and Laboratory Services Branches were outlined by W. H. Price. An invitation to tour all facilities was given to the participants to acquaint them with the scope of laboratory work.

After brief recess, H. M. Martin, Chief, Hydraulic Laboratory Branch, divided the personnel into 2- and 3-member groups with assigned guides for a general tour of the laboratories. At 11:30 a.m. these groups assembled at the 5,000,000-pound testing machine where Concrete Laboratory Branch personnel broke an 18- by 36-inch concrete test specimen.

The meeting convened at 12:30 p.m. for discussion of subjects listed under the main agenda topics of Hydraulic Structures, Hydraulic Equipment and Closed Conduits, Sediment Research, Instrumentation, Analogs and Data Processing, and Special Tests and Summary.

HYDRAULIC STRUCTURES SESSION

August 9, 1960
12:30 to 2 p.m.

Mr. Martin, as presiding officer, introduced Bureau staff members who had not been present at the morning session, and briefly outlined previous conferences held by the Corps of Engineers and the Bureau of Reclamation that led to the present conference. The importance of discussing and freely exchanging experiences and ideas on future needs concerning laboratory techniques was emphasized. The first topic of discussion was:

Hydraulic Measurement of the Effect of High Velocity Flows at Surface Irregularities

Colgate introduced the topic by discussing the Bureau's experiences at Glendo Dam. Model studies of the outlet works stilling basin had been made, and pressures were measured on the chute blocks and baffle piers with the usual water columns. No alarming conditions were noted, and the structure was built. However, soon after moderate head operations started, a heavy thumping was noticed and movement occurred on the wall separating the stilling basin from the powerhouse tailrace. Motion pictures illustrated the action within the basin and showed a movement of 3/16-inch at the top of the wall. The operating head was 127 feet. Reasons for the wall movement were sought by Bureau engineers, and it was thought that the formation and collapse of large scale cavitation envelopes at the chute blocks and baffle piers resulted in heavy pressure surges that were transmitted to the wall. Examination of the dewatered prototype basin showed that severe cavitation erosion had occurred on the blocks, and gave weight to this argument. New model studies were made of the basin, and streamlined blocks were developed. A 1:80 scale chute block was then tested at prototype velocities in a water tunnel. Instantaneous pressure measurements indicated that no cavitation would occur on the top or side surfaces. A large envelope occurred downstream, however.

Douma asked if the movement was actually related to cavitation, or if it was due just to pressure surges developed in the violent hydraulic jump. He stated that at Texarkana Dam they lost a wall lying between two jets in a basin due to fluctuating loads induced by jumps on either side of the wall. The wall was of simple cantilevered, reinforced concrete design. It was replaced with a more heavily reinforced one, which has performed satisfactorily.

Ball said that the wall movement could be correlated with the thumping in the basin, and the only explanation for this thumping appeared to be from forces created by large-scale cavitation collapse. He pointed out that after the streamlined blocks were in the prototype basin, the vibration and thumping were not present until quite high releases were reached. Douma noted that streamlining the blocks and piers would change the jump appreciably, thus affecting pressure surging within the jump. Ball agreed, but believed that the jump would become more violent, and if the thumping were due to this violence, it would have become worse instead of better in the prototype. Murphy injected the thought that streamlining the blocks and piers merely changed the cavitation so that instead of occurring on the surface there would be greater tendency for large-scale envelopes downstream. Therefore, it would be possible for streamlined blocks to produce worse conditions than nonstreamlined ones.

Murphy cited cavitation studies on blocks in Bluestone Dam stilling basin. He stated that they did not as yet know how to interpret model data in terms of prototype results when working in low-pressure ranges with appreciable pressure fluctuations. They do, however, regard average model pressures equivalent to minus 20-foot gage (sea level), with lower transient pressures for a third or more of the time, as cavitation-producing conditions in the prototype. This rule generally is used in their model data interpretation.

Model and prototype studies at Bull Shoals Dam, where cavitation occurred on ascending steps in the stilling basin floor, were related by Campbell. After damage was discovered on the prototype structure, the steps were rebuilt and a pressure cell was placed in the repaired area. The prototype pressure fluctuations measured by the cell were severe and included extreme negative pressures. The average of the cell pressures was in good agreement with the average model pressures.

TVA's experiences with the Wilson lock with a 100-foot lift were presented by Elder. Extensive model studies were made, including five series of tests embracing the anticipated prototype conditions. To date, two of these conditions have been obtained and tested on the prototype structure. Nineteen pressure cells were placed at critical locations in the filling culverts. The data showed that average model and prototype pressures were in excellent agreement, but that the transient pressure results were less conclusive. One reason was believed to be that hydraulic coupling difficulties were present in the model piezometers. Dale amplified on this subject by stating that the cell diaphragms should be placed as closely as possible to the area being measured, so that no coupling, damping or oscillations could occur.

Theus and Webster described model baffle pier tests, in which they found good agreement with the premise that an average pressure of -20 feet of water indicated cavitation pressures about 30 percent of the time, even through appreciable piping was required between the piezometers and the transducers. They stated that on the John Day Lock Model they had flush-mounted cells and cells with 6-inch-long leads. Instantaneous pressures agreed within 5 feet of water with the flush and remotely mounted cells. The frequency of oscillation was about 5 per second.

The experiences of DTMB were related by Brownell. Generally, they find it desirable to place the cells as close as possible to the surface, to reduce or eliminate any system resonance or damping. Great care was taken in placing the pressure taps in the wood and wax models commonly used, so that surface irregularities would be avoided.

In connection with discussions on connecting systems, resonance, and damping, Theus stated that the Bureau of Standards and the Statham Laboratories have publications describing these phenomena and presenting design data so their effects can be evaluated or avoided. Simmons pointed out that NACA reports were also available.

Damage to pressure cells in the vicinity of cavitation in model and prototype installations has been experienced by the Corps, TVA, and DTMB. It was agreed that the failures were due to overpressure cycles rather than underpressure ones. In the Wilson lock prototype tests, a 75-psia pressure cell which was located on the bottom seal face of the culvert filling valve was destroyed. This cell was replaced with one which was rated at 1,000 psia and which the manufacturer said was capable of withstanding 2,500-psia pressure without destruction. This cell was also destroyed and the destruction occurred almost instantaneously with the start of the valve opening. The operating head on this valve was approximately 98 feet.

Surface roughnesses on boundaries exposed to high-velocity flows were discussed by Webster. At the Dalles Dam, bugholes in the concrete surfaces in the curved invert at the entrance to the lateral culverts in the navigation lock showed areas of local cavitation immediately downstream from the bugholes. Webster asked what would happen if these same sized surface irregularities were in the direct path of high-velocity flows, such as tunnels in regulation outlets. No specific answers were forthcoming, but it was generally agreed that trouble could be expected. Campbell mentioned that this question was important in establishing surface construction tolerances, and whether or not it was realistic to demand very smooth surfaces.

Ball related the Bureau's experience on walls in line with the flow. Bugholes 1/2-inch or longer in the direction of flow on an otherwise quite smooth surface produced local cavitation. These holes were in concrete walls a short distance downstream from high head gates. Whether or not cavitation would occur at the same sized discontinuities in some other locations depends upon the local velocities near the surface and the ambient pressures.

The Beach Erosion Board has studied shock due to waves breaking on structures and transient pressures were measured with pressure cells. The forces and methods of measurement were thought by Fairchild to be of interest to others in the hydraulic field. Brownell added that slamming pressures on ship hulls in waves had been studied by DTMB, and unclassified material could be obtained by writing to the Model station. Schuster commented that a list of unclassified DTMB reports was circulated within the Bureau.

Peizometer openings and their effect on indicated pressures were discussed by Thomas, and he asked if there was any recent work or information in the literature on them. Several ASME publications were mentioned.

Vortex Flow and Model-prototype Similitude

Murphy introduced the subject by describing Corps of Engineers lock structures, which today are being built larger, higher, and quicker operating than in former years. Model studies of these structures have often failed to show vortex action at the culvert entrances, and yet the prototypes experienced heavy vorticity. He posed the question of why this descrepancy existed between the model and prototype, and what observations or tests could be made to eliminate or breach it.

Similar problems at lock culvert entrances in floors were described by Nelson. He pointed out that if rotational flow capabilities were present, vorticity would probably result, and once started the action would probably be persistent. A correlation between model and prototype actions may exist because small dimples have been noted in the models and these were found to be 3- to 8-foot-diameter prototype vortices. Murphy concurred that dimpling has been observed and that it was a definite indication of prototype vorticity. He added that in making model studies, extensive and realistic forebays should be provided so proper approach conditions will be produced. Vortex triggering can easily occur, and precautions are needed to prevent erroneous formations in this model, and also so that sufficient model detail and extent is present for producing conditions that will actually occur.

Extensive studies by Denny of the British Hydromechanic Laboratory were enumerated by Thomas. Denny started his work using small models, and progressed to larger and larger ones. By now he may have accumulated considerable data on model-prototype similitude. Thomas observed that Denny said appreciable depth would prevent vortex action at inlets. Thomas cited a case at Hoover Dam where a vortex persisted at depths of 200 to 300 feet.

Lang and Thomas described Priest Rapids Dam, where well-developed vortices occurred at the spillway control gates. On the left and right sides of the spillway, single vortices occurred at each gate, the ones on the right moving in one direction and the ones on the left in the other. Two vortices occurred at the center gates, one at each end, moving in opposite directions. Apparently, no difficulty is caused by these very prominent vortices. Gildea noted that radial (Tainter) gates were used at Priest Rapids, and asked if radial gates induced vortex action more quickly than slide gates. Thomas believed they did, possibly because of their curvature. Murphy suggested that the pier or wall geometry upstream from the gates would be more important than the gate's shape. He pointed out that the vortex action in this type of installation was largely due to a difference in approach velocity at the center of the gate and near the walls, due to boundary drag.

Campbell presented a chart showing the incipient vortex formation or dimpling seen in the laboratory and the fully developed vortices usually seen in the field. Rankine's analysis of vortex flow was included. Campbell showed that surface tension and viscous shear were important in vortex modeling, and that these factors were not accurately reproduced in Froude modeling. More theoretical analyses, model testing, and prototype observations are needed so better interpretations can be made from model studies.

Model and prototype experiences with Shadehill and Heart Butte morning-glory spillways were presented by Peterka. These spillways operate under high submergences, and vortex action was a problem. Model studies showed that rafts or covers were ineffective or impractical for controlling the vortices. Piers performed better, even though in some cases they were only one-third as high as the submergence. The final designs developed by model tests used crest piers to limit the size of the vortices. Prototype tests showed the expected vortices, and they were powerful enough to swallow large chunks of ice, 55-gallon oil drums, and a 30-foot tree. In spite of their size and power, they did not cause objectionable operation.

Brownell referred to DTMB's tests of wake surveys at the stern of ships, as measured by spherical pitot tubes and pitot rakes. Much of their earlier work was done with a 13-hole spherical tube. Lately, a 5-hole tube has been used. A publication by Dr. Pien should be available through the Office of Naval Research or DTMB.

A large vortex that occurred at the corner of a side outlet sluiceway during model studies of Woodston Diversion Dam was discussed by Carlson. In this case, the vortex interfered with the sediment control being sought. A curtain wall in the model eliminated the vortex. A recent examination of the full-sized structure showed that the curtain wall was performing well, and that no vortex was present. Model-prototype conformity was excellent in this case, where a 1:5 scale ratio was used.

It was concluded that care must be taken in designing models and in looking for relatively tiny dimpling which would indicate vortex action. This is particularly true in models where the individual components, such as gates, are small. If indications of vorticity occur in the model, it will almost surely occur strongly in the prototype. Additional basic information will be required before adequate model-prototype similitude can be established for a wide range of scale ratios and model sizes.

August 9, 1960
2:15 to 3:45 p.m.

Protective Materials Studies in Model and Prototype--Structures, Conveyances, Shorelines, Riprap, and Other Means

Martin, in a question to Murphy, asked if there are data available for laboratory-prototype comparisons.

Murphy asked if he was speaking of riprap data, and indicated information to date had been issued in a report on the Old River Low Sill Control Structure. They are beginning a series of tests on riprap below stilling basins. They are trying for general design data for various heights of dams, and lengths of stilling basins. Tractive force theory has been applied, but the subject needs considerable research with regard to uplift forces.

Campbell noted that downstream of stilling basins riprap normally washed out on the side slopes where waves may be the cause. The kind of wave, its amplitude, and frequency, it was generally agreed, needed much additional study.

Carlson discussed Bureau studies of wind waves in canals with regard to erosion of bank.

Campbell asked the group what information on stilling basin waves of the type caused by energy dissipation was available.

Thomas mentioned past studies on Grand Coulee spillway buckets and exit channel. Measurement of this type of wave is an extreme problem caused by the type of equipment required. He outlined the method of applying a grid to a stilling basin wall and photographing the wave results by still and motion pictures.

Theus mentioned data from Dorena Dam near Eugene, Oregon, where varying sizes of riprap were used. Some riprap failed and some did not; velocity data were obtained but no wave measurements are available from this site.

Murphy asked if the Bureau had design criteria other than the preliminary report Hyd 409, and whether any revision has been indicated since that time.

Peterka answered that any additional data would necessarily be conditioned by scaled relationships from hydraulic models. These, at present, are being geometrically scaled although it is known the shape factor is important. The fall velocity is not being used because we believe that the stone sizes scale up on a geometrical basis.

Murphy indicated his belief that weight as well as size may be very important and Peterka added that the size of rock is not well defined.

The importance of gradation of riprap material was mentioned by Murphy, and Campbell suggested that placement, bedding, and the type of protective filter would have an important bearing on the resistance of the riprap to water action.

It was generally agreed that there were so many factors that study should be for the purpose of eliminating factors that have only medium to small significance.

Peterka stated that he had taken the work of Gildea and compared the data to the curve in Hyd-409 and found that the riprap reported good fell on one side of the curve and the bad fell on the other.

Gildea said weight similitude had been used in these studies with crushed rock in the model representing quarry rock in the prototype. Gravel used in the model represented rounded river rock. Gradation in the model studies was on the basis of prototype specifications.

Martin asked a question about a reinforced concrete channel with high velocity discharge transitioning to a slow velocity channel without a stilling basin.

Gildea said that this system would use a 1,200-foot long riprap energy dissipator to change the velocity from 35 to 10 feet per second and that the size of riprap had been determined.

Campbell asked if the prototype had been built and was answered in the affirmative, but Gildea explained that the larger sizes of riprap had been grouted.

Douma said he believed that some projects are too conservative in the supply of riprap below a stilling basin and that improvements in grading of the riprap should be made for best economy. He suggested provision of a horizontal as well as a vertical grading of the riprap. For example; the first 50 feet downstream of a stilling basin be supplied with large riprap, the next 50 feet, a medium size riprap, and the last 50 to 75 feet with smaller material.

Martin wished to know what was observed in the model and prototype to best define riprap sizes.

Peterka explained his belief, by the use of a sketch on the chalkboard, that we are considering the wrong velocity, especially for the end sill of the stilling basin. Since normal use is a Q/A velocity for definite riprap sizes, we may be missing the actual cause of the force disturbing the riprap.

Campbell agreed that turbulence is a probable cause of riprap failure on the bottom, but there is a different problem for the sides and bottom. Both wave height and velocity were mentioned by Douma with wave height probably the biggest unknown. He mentioned that 3-inch waves would cause no particular trouble, but a great deal of damage can occur with 5-foot waves.

He suggested that a program of measuring wave height be undertaken and then raised the question whether the effective wave height should be taken as the average or maximum wave height.

With regard to this proposal, Campbell has started a correspondence inquiry for information on riprap failure for correlation with wave height.

Campbell asked if we have information on wave heights below stilling basins. Peterka raised the question of variability of wave heights. Fairchild offered a criterion of the Beach Erosion Board that considers the significant wave height to be the average height of the highest one-third of the waves. He suggested that we might classify waves according to this criteria and then correlate wave height and period to the riprap size on the bottom or along the shore.

Gildea remarked that our problem may not be waves as such but velocity and pressure surges, correlation of velocity change and waves might be a more fruitful procedure.

Murphy then cited a riprap failure in the Old River control structure model where velocity and waves were low, but turbulence seemed to have caused riprap failure.

Brownell suggested that possible pneumatic dampers might be used to decrease wave height. David Taylor Model Basin is presently undertaking a study of simulated short crested or confused sea waves. These studies are to be made in a basin 240 by 360 feet and will measure direction, magnitude, and energy of the wave spectrum using the theory of Barber from New Zealand for the directional wave spectrum.

Six capacity-type wave probes on a rotating arm will be used to measure the waves. Brownell suggested that we inquire on the availability of wave information from the DTMB as applied to our studies. The question arises as to the similarity of sea waves and stilling basin waves.

Any surface disturbances may cause damage to the side slope cover, but may not effect the bottom cover.

Barbarossa suggested that the duration of the flow may have a major part in causing failure of protective materials.

Martin asked Brownell if a survey of the energy spectrum would be necessary and was answered by Mr. Fairchild to the effect that the Beach Erosion Board has developed and is now improving an instrument (a Wave Spectrum Analyzer) for measuring electronically both the total energy and the energy distribution in a spectrum of wave heights and wave periods. Both Barbarossa and Douma said that bank protection was a much larger problem in the Corps of Engineers' work than stilling basin protection. In one instance, riprap thicknesses of 12 and 36 inches were suggested by separate offices and because of a lack of information, a 24-inch thickness was selected arbitrarily.

Thomas, in summarizing the discussion, asked what is the purpose of protection? He suggested that they might fall into categories of (1) protection of the upstream slope of the dam; (2) exit channel protection of a stilling basin sideslope; (3) exit channel bottom; and (4) river channel protection. He agreed that the velocity fluctuation might be predominantly the cause of failure, as these fluctuations produce alternating pressures within the protective material.

Murphy wished to know if most of the available data were concerned with straight channel or were curved channel data available.

Thomas said most all were straight.

Douma suggested that we should concern ourselves with protection for velocities in the order of 10 feet per second or greater, and that tractive force approach may work, but in any case, the velocity range should be indicated.

Barbarossa noted this was a highly specialized study.

Thomas suggested the study should include the direction of waves and its impingement on the riprap.

Campbell mentioned that impact pressure was high for a breaking wave, but not for a clapotis, normally encountered in our work.

Martin summarized the discussion and noted that it may be necessary to request assistance from DTMB and the Beach Erosion Board to further our studies on the energy spectrum of the waves.

Hydraulics of Large Conveyances--Basic Fluid Mechanics Concepts--Instrumentation

Thomas outlined the program and the necessity of obtaining data to provide a basis of altering design procedures with reference to large canals. He explained that operational tests of the Central Valley Project canals had shown in one case a 20 percent deficiency in capacity. Because of the seriousness of the problem, a study group proposed that the deficiency be analyzed and an attempt be made to define the significance and separate the causes of the deficiencies. The losses would probably be made up, in the main, by surface roughness of the boundary, but structure losses should be separated. From the analysis, field studies were performed to measure head losses caused by pier-supported bridges and other structures. Attempts were also made to measure head losses in short straight reaches of the Delta-Mendota Canal. From these preliminary investigations, a more elaborate field test program was outlined and a portion accomplished during the past year. Losses caused by bridge piers, both timber bents and articulated concrete piers lend themselves to laboratory study. Models are being studied to determine the cause of water surface oscillation at the concrete piers and head losses for the timber bents.

Thomas explained that air test facilities to determine the relative roughness of various linings were in preparation.

Thomas illustrated his description of this study by the use of motion pictures that showed the instruments used in the field for head loss measurement. During the movie, Campbell suggested to Thomas that resonance of the vortices produced by articulated concrete piers with waves reflected between the piers might cause water surface oscillation. At the conclusion of the movie, Thomas further explained the extent of the investigation in connection with measurement of head losses in straight canal sections and in bends and the velocity distribution for the determination of boundary shear. With regard to the velocity distribution study, Thomas mentioned that the Dumas-type screw meters were to be used to obtain a more precise measurement. Thomas then requested suggestions as to how our procedures in both the laboratory and field might be improved. Nelson was asked by Thomas if he thought that the pressure differential gage proposed for sediment study might be useful in measuring the head losses in the prototype canals.

Nelson replied that the gage was very sensitive, but that some difficulties had been encountered in its use. Dynamic effects of turbulence and currents in a field installation would mask out the effect of pressure differentials due to variations in sediment concentration. However, the gage may be adaptable to laboratory work.

Douma asked what was wrong with using point gages and an engineer's level.

Thomas explained that most of the canal water surface fluctuated to possibly 0.25 foot of water, thus making the surface very difficult to read with a point gage.

Thomas then explained the stilling well type of water surface gage with Prandtl pressure head tube.

Martin asked if the Corps of Engineers had made any such studies of their ship canals.

Murphy indicated that the Chicago Sanitary Canal might offer information. Ship canals are not normally concerned with this particular problem because a fixed discharge capacity is not a design requirement according to Douma.

Thomas completed his description of the velocity distribution-head loss measurements that are being performed in the Columbia Basin Project. Head loss in bends was mentioned, and Campbell remarked that he did not think anyone knew the loss for an open canal curve.

Thomas pointed out that through the present studies, we hope to evaluate or compare losses of multiple curves with the losses for essential straight reaches.

Martin then summarized the experience of our canal design in which small-to medium-size canals seem to have adequate capacity, while deficiencies were noted for the large-lined canals on flat slopes. Thomas added to this summary the range of canal size from approximately 1,000 to 5,000 cfs.

HYDRAULIC EQUIPMENT AND CLOSED CONDUITS SESSION
August 10, 1960
8 a.m. to 9:30 a.m.

Chairman Martin opened the session by introducing the subjects to be discussed. He briefly reviewed the topics to indicate the areas of the problems to be explored and asked Simmons to start the discussion by introducing a typical problem in Item 1.

Energy Dissipation in Closed Conduits--Laboratory Studies of Sudden Enlargements; Other

Simmons sketched a farm turnout used to supply irrigation water from a high head pipeline under 400 feet of head. The flow was controlled by a gate valve and discharged into a larger pipe immediately downstream from the valve, creating in effect a sudden expansion in the conduit. The larger pipe flowed full with a back pressure of about 5 feet of water. The pipes were alined on a common center line. Under these conditions, Simmons explained that the upstream pipe diameter, d., required a downstream pipe diameter, 2d., to provide sufficient area for energy dissipation. If the downstream back pressure was increased to 15 feet of water, the downstream pipe diameter could be reduced to 1.75d; under these conditions, cavitation occurs in the downstream pipe and air is introduced at the top of the larger pipe just downstream from the valve to reduce vibration, noise and cavitation intensity. Tests using a weak concrete lining in the downstream pipe showed that no damage to flow surfaces occurred during the testing period. Simmons then stated that the testing had progressed sufficiently to make general studies of this type of energy dissipating structure. The present testing equipment in the Laboratory uses 3-inch pipe upstream and downstream from the gate and in this particular test an orifice is used instead of a gate. The tests are concerned primarily with determining the coefficient of discharge of the orifice for heads of about 250 feet and a back pressure in the downstream pipe of about 65 feet of water. Simmons also indicated that the model had been set up for demonstration but that, because of difficulty with the pressure cells, there would be no point in having the group see the performance of the energy dissipator.

Martin asked the group a general question, "How do you determine the size of pressure cell necessary to prevent damage or loss of the cell without actually trying the cell in the test equipment?"

Elder answered and said that in his experience you always need a cell larger than any made. On a similar problem, a 2,500-psi cell was destroyed. He said that according to certain theories the plus pressure might reach 100,000 psi or even 750,000 psi. He felt, however, that not much could be learned by measuring pressures of this magnitude and that the main interest was in the low pressures. If a cell were installed to measure pressures of the order of 100,000 psi, it would be impossible to detect low pressures of the order of -20 feet of water, the range of greatest interest.

Douma injected another question as to whether the measurement of these high pressures was not of more academic interest than practical.

Ball stated that it is sometimes necessary to know the value of the high pressures because of the need for including high impacts in the design of the structure. On the other hand, measurement of pressures in the 100,000-psi range probably indicates that something is wrong with the pressure cell or the manner of connecting it to the piezometer. Ball felt that the measurement of the collapsed pressure of a cavitation bubble was not nearly as important as the high pressure surges which occur in a structure. This is particularly true since no data are available on high pressure surges on the type being discussed.

Murphy stated that pressure cells tend to give the pressure over an area larger than occupied by a collapsing bubble and that even under conditions such as these the measured pressures are often higher than can be accounted for by the operating heads.

Campbell sketched a pressure cell on the blackboard and indicated that it was not too important to know whether the pressure at the point of collapse was 100,000 psi or 200,000 psi. Either pressure would be destructive. He also stated that it should not be too difficult to compute the size of diaphragm necessary for use on a pressure cell to measure any desired pressure according to known theory of circular plates. Campbell then drew a sketch of the Detroit Dam slide gate outlets to illustrate how high pressures occur in a full size structure and where the damage could be expected and where pressure cells could be installed to measure low pressures that could cause cavitation. He indicated also that a jet emerging from beneath a slide gate with a small opening into a channel which was wider than the gate produced a sudden expansion effect. The jet impinged on the downstream walls and caused cavitation erosion. Further downstream, where the jet reflected from the wall to the opposite wall, there was another area of damage but of considerably less magnitude.

Martin then asked for other examples of energy dissipation in closed conduits.

Douma asked whether the tests described by Simmons were made with actual erosion taking place in the downstream pipe.

Simmons stated that the downstream pipe had been lined with weak concrete and that the evaluation of the energy dissipating device was based on actual erosion rather than on pressure measurements. The depth of erosion or the lack of erosion was used to make the recommendations for the field structures.

Douma stated that he felt that more of this type of testing should take place and that the structures should be designed on the basis of actual erosion tests rather than on predictions made from pressure measurements.

Webster commented on the fact that poor concrete or weak concrete as used in the laboratory tests might be misleading. As an example, he said that much of the cavitation damage found at Detroit Dam had been caused by poor concrete. On similar structures where the same type of action might be expected, no damage had occurred because the concrete was of better quality. Since the damage had occurred at Detroit Dam, two of the outlets had been lined with steel; however, they have not been operated sufficiently to determine any damage on the steel liner. Campbell raised the question of damage occurring where the hollow-jet valve jets impinged on the floor of the Navajo outlet works stilling basin which was shown to the visitors on their tour through the Hydraulic Laboratory. He mentioned that the Bureau's tests at Guernsey showed that high velocity jets on concrete produced erosion. He wondered whether pressure measurements had been made beneath the jet to determine whether positive or negative pressures occurred in the impingment area.

Peterka stated that piezometers had not been installed in this particular model but that extensive measurements had been made on models of similar structures and that no negative pressures had been found. All measurements indicated that the pressures were positive and that they were not particularly high and had no effect on the design of the floor. In most cases, the pressure beneath the jet amounts to only 3 or 4 times the static head created by the water depth in the basin.

Thomas said he would like to indicate a method of measuring maximum pressures by means of a special device connected to a piezometer opening. He drew a sketch on the board showing a tube connected to the piezometer opening and a check valve within the tube set to allow the maximum pressure to force water into the water manometer and prevent its return when the pressure was reduced. In this way, the maximum pressure surges caused a buildup of water in the manometer tube and the water rose above the usual level. Thomas stated that it would be possible to reverse the check valve so that low pressures could be measured on the same piezometer and on the same equipment.

Brownell commented on the device and felt that it was good technique. He also suggested that pressures could be measured by means of known pressures introduced into the system in such a way that they balanced the pressures to be measured. In other words, a pressure would be forced into the system until it balanced the pressure to be measured. He said he felt that this would require some technique in most cases but that the idea might be used to advantage.

Thomas stated that this method with some variations had been used in the past and had been found successful for simpler pressure measuring problems.

Application of Air Testing to Hydraulic Model Studies

Martin asked Colgate to introduce the subject and explain the use of air models.

Colgate indicated that in the Bureau Hydraulic Laboratory we use low velocity air as a test fluid and that we have found the air test to be valuable because the air models are simple and light and can be tested with considerable speed. He indicated that it would be much simpler to make changes in a flow surface which had not been submerged or wet than in one which needed to be watertight and water resistant. On the other hand, he indicated that differential pressures of say 2 inches of air used to represent 500 feet of water in the field could be subject to great error unless care was taken in the testing procedures. He raised the general question as to whether the accuracy of air models was sufficiently good to be reliable and then stated that better instrumentation was needed to be sure the answers obtained were in reasonable limits of accuracy. He mentioned that air had been used as the test fluid on a model used to determine the downpull on gates.

Murphy raised the question as to whether the air model setup in the Laboratory represented true conditions, particularly in respect to the fact that turbulence in the air in the room could affect the results of an intake structure such as the one attached to the air testing setup at the present time.

Colgate said that normal turbulence in the room would not affect the results and that he had not been able to notice any difference due to quiet or turbulent air at the entrance to the device being tested.

Murphy inquired as to the air velocity used in the tests.

Colgate indicated that velocities should be less than 300 feet per second to avoid compressibility effects and that they should be above 50 feet per second so that measurable differentials could be obtained in the test structure. He felt that an average velocity might be 100 feet per second and that this would supply sufficient velocity for accurate testing.

Simmons indicated that it would be desirable to keep the velocities fairly high because the Reynolds number would then be high and more reliance could be placed on model-prototype similarity.

Brownell said that the David Taylor Basin had air testing facilities of several types and sizes and that they were used in fundamental studies of boundary layer problems. He said they had used one wall of the tunnel to investigate boundary layer effects and that the hot wire anemometer was used to check velocity fluctuations. He said he felt that in their experience air models were inexpensive and on the other hand were very fruitful. He said it was not necessary to have expensive equipment and that a 6- to 9-foot-diameter fan placed in a simple tunnel open at each end could be used to obtain valuable information.

Martin indicated that certain laboratories had found low velocity air testing to be of great value and that the laboratory at Iowa for example had six air tunnels available for testing purposes.

Murphy said that the Vicksburg Laboratory had started several times to design air testing facilities but that each time they wound up taking all the advice that had been offered them with the result that their proposed air tunnel became a giant structure. As a result they had never gotten started in air testing. He felt, however, that, from what he had seen and heard, a much small testing facility would do the job they had in mind.

Thomas brought up the question as to whether air could be used to make movable bed studies.

Carlson commented if this could be done the testing costs could be reduced considerably.

Fortson said that he understood that the Russians were using air in movable bed tests.

Murphy commented that the British also were doing work in this field.

Martin commented that the general feeling is that the Russians are leading the world in sedimentation studies of all kinds.

Colgate inquired of the assembly in general if they had had difficulties in using the hot-wire anemometer.

Brownell said that they had had trouble in water tests and that dirt had collected on the wire to affect the readings. He also said that high-velocity water flow often broke the wire. Therefore, they had used the hot wire in water only where the velocities were very low. He said they were also trying to use a device known as the hot-film anemometer and were trying to develop testing techniques. So far, he said, the hot film had not been too successful but they were now developing improved techniques.

Similitude Problems of Aeration in Closed Conduits

Dexter started the discussion by inquiring as to whether data had been collected on the air demand for closed circuits.

Campbell said that the Corps of Engineers had collected a considerable amount of data on air demand with a partially opened slide gate and had suspended collecting field data. He said actually what was needed was more research on how to apply or use the data already taken or available. He mentioned three separate phenomena as the gate opens. For small openings, the spray of the jet entrains a large amount of air; with a medium gate opening, the rough water surface of the part-full tunnel drags air along; and when a jump exists in the tunnel, the jump itself entrains air.

Webster said that his office had planned to get data on some structures for correlation with the model but that they had not been able to obtain any to date.

Douma indicated that the usual design practice is to install an air vent in the prototype design without too much concern about capacity.

Because of the fact that air can move at great velocities, the vent size is not critical; however, he said sometimes the vents do whistle because of the high velocities passing through them.

Simmons indicated that there are different kinds of air vent problems and that even through the Corps feels the problem is pretty well solved from a practical viewpoint, there are other ventilation problems which have not even been touched.

Douma agreed that the Corps of Engineers do not have the variety of problems that the Bureau, for example, has and that a good deal of research should be done to solve the problems.

Peterka stated that air demand is often related to flow boundary geometry and that air quantities vary because of the shape of the conduit itself.

Campbell indicated that he thought in cases where negative pressures had been measured below the gate, it was possible to calculate the air flow necessary and drew a sketch on the board to indicate the assumptions made. He said that in the case of free water surface drag of the air, they had found it was impossible to arrive at the quantity of air measured with any reasonable assumptions of water surface roughness.

Thomas indicated that the problem is not simple and that in air flow calculations the fact that the flowing air changes the differential pressure should be taken into account. In other words, a certain differential produces a certain flow of air but as soon as the air starts to move the differential changes and the air quantity therefore changes.

Gildea indicated that he was not clear as to the arrangement of these structures and asked that a sketch be drawn.

Simmons drew 3 sketches on the board showing 3 typical problems with regard to venting the conduit downstream from a control gate. He said that at the present time the Bureau Laboratory was running tests to correlate model-prototype air demand relations. The first was a slide gate with the vent in the roof of the conduit just downstream from the gate. The second showed a jet flow gate discharging into a circular tunnel and the air vent was placed in the crown of the conduit just downstream from the gate. He also indicated another method of venting the tunnel where the top of the downstream conduit was partitioned to provide a separate air passage along the crown of the tunnel.

Campbell indicated that the maximum air demand at several projects occurred at larger gate openings. The secondary maximum caused by jet spray at small openings was less. He said, however, that results on Pine Flat Dam with very high head indicated that the maximum caused by jet spray at small gate openings exceeded the other maximum at large gate openings.

Elder referred to air demand data which had been obtained by the TVA for a Howell-Bunger valve operating in an open channel tunnel. He said they had obtained no new data.

Peterka drew a sketch on the board showing the air problem encountered in morning-glory spillways and directed his remarks toward Campbell's previous discussion of the distribution of velocities in the air space above the water in a partially full tunnel. He described experiences where a handful of straw dropped down the face of a headwall past the downstream end of a tunnel flowing partially full caused the straw to be drawn into the tunnel because of an upstream flow of air in the uppermost crown area of the tunnel. On the other hand, a heavier object dropped down the face of the headwall, such as a piece of wood, was not drawn into the tunnel but was blown downstream to some extent by the air moving at high velocity at the air-water interface. This crude experiment indicated that even though air was being supplied through the vents at the upper end of the tunnel, there was a definite movement and separation of air moving both upstream and downstream at the downstream end. Air in contact with the water surface moved downstream but above this a layer of air was moving upstream along the crown of the tunnel. Peterka suggested to Campbell that events of this type probably accounted for the poor results obtained when calculating air demand and estimating the vertical velocity profile of the air in the tunnel.

The meeting was then recessed and the group went into the Hydraulic Laboratory to observe the tests on the Trinity gate model and to see firsthand the air demand for a structure of this type.

SEDIMENT RESEARCH SESSION
August 10, 1960
9:45 to 11:30 a.m.

Materials and Measurements in Movable Bed Hydraulic Model and Prototype Studies

The session was opened with a discussion by Mr. G. B. Fenwick regarding unusual problems encountered with movable bed models at low temperatures.

Fenwick stated that model verifications which have been made with summer water temperatures are not necessarily valid at low water temperatures. Between approximately 55° F and 45° F there occurs a marked change in the appearance and roughness of the bed. On occasions, it has been necessary to install steam pipes to finish tests in winter time that were begun in warm weather. Fenwick is not sure these bed formation changes are due entirely to the change in water viscosity and asked if any observations regarding temperature change effect on prototype had been made. He indicated the Corps of Engineers planned to conduct tests to determine temperature effects on bed conditions with water temperatures varied from a high of approximately 85° to a low of approximately 34°F. Various types of sands would be used in this study. The flume in which it is planned to conduct the tests is 75 feet long by 3 feet wide, and has a continuous weighing device to determine stability. Stability is assumed to be the point where sediment inflow is equal to sediment outflow. It is planned to conduct tests for a series of temperatures, bed conditions, and discharges to see what information can be obtained from them.

Fenwick said Dr. Straub of the University of Minnesota had conducted some suspended sediment tests in which he had varied the water temperature, but that he did not think Dr. Straub had reported regarding bed changes. Fenwick said he had heard that Dr. Straub also had made tests involving changing viscosity by the use of chemicals without changing temperature, but that he had not seen a report of such studies.

Carlson stated in studies in Dr. Straub's laboratory, sugar had been used to change the viscosity of the water and the tests have been reported in a thesis by Neubaur. He also made the observation that data taken on the Colorado River below Hoover Dam had shown higher concentrations of suspended sediment in winter than in summer, and indicated viscosity changes alone did not appear to account for the total increase in suspended sediment. He added, in the Colorado River studies the general size of suspended sediment was similar to sizes found in the bed material.

Campbell asked if the sugar had changed the density of the water.

Florey confirmed the fact sugar will change the density of water.

Fenwick said bed changes due to temperature effects had been observed both in models with coal beds and in models with sand beds. He said removing the large fraction from coal beds seems to have the same effect as a decrease in water temperature and results in excessive riffles in the bed. To eliminate the riffles, it is necessary to add a little material to 1/4 inch in size.

Carlson stated the Bureau of Reclamation had performed few movable bed model studies using coal as bed material and the temperature in most of their model studies is usually fairly constant.

Murphy expressed the opinion this is more than a model problem, and at St. Louis they feel they have different flows at a given stage during winter and summer, and colder water generally results in a higher stage for the same discharge.

Carlson agreed with this and said a temperature change may cause a bed change from dunes to ripples, or vice versa, and at a given temperature the change may occur at a different hydraulic condition than at another temperature.

Fenwick stated than Vanoni and Brooks had published a valuable report on this subject, and that inclusion of more temperature variations would have improved it greatly.

Carlson asked about the type of materials in general use in model studies to duplicate prototype bed sediments.

Fenwick said the Corps usually uses coal, as they have it in sufficient quantities, but in a recent study, they had used sand because they believed it would better represent sand formations in the particular prototype. He said it was necessary to tilt the sand-bed model a considerable amount to get sufficient movement and they did not have data by which to verify the model study.

Carlson asked if the gradation analysis changes with time when coal is used for model sediment.

Fenwick said that the Corps did not recirculate the coal through pumps, but the material was collected in tailboxes and was refed by hand in a wet condition into the upstream portion of the model. He indicated when a model was dry, it was necessary to spray the coal bars with water and aerosol to keep them from floating.

Carlson stated plastic material obtained from Dow Chemical Company worked well as suspended sediment after the oily coating on the material had been removed. The specific gravity of the material was approximately

1.06 compared to the 1.35 to 1.38 specific gravity of coal. In general, the Bureau of Reclamation is recirculating sediment in model studies.

Fenwick inquired about the type of pumps the Bureau of Reclamation was using for recirculating sediment.

Carlson answered that two axial-flow turbine pumps have recently been revised so clear water under pressure is used for bearing lubrication and the Bureau has recently obtained a centrifugal sand pump. He said that impellers on small turbine pumps have been coated recently with epoxy resins and tests are being conducted to determine benefits of the coatings. He further stated jet pumps had been designed and used and had been found to work well.

Fenwick said coal worked well for bed material, and that salt had been used on occasion to increase the density of water. He indicated good results with bed movement at increased water densities, but added, considerable trouble resulted from rust. He asked if bentonite had been used successfully to change the density of water.

Thomas said that at Delft, Holland, bentonite had been used to increase water densities, but some unexplained troubles had occurred when the bentonite tended to flocculate and mix with bed sediments.

Carlson stated that information had been received from the National Hydraulic Laboratory in Chatou, France, where ground apricot pits were being used to simulate sediments in model studies. He further stated from studies at the Bureau of Reclamation, it had been found that sodium-base bentonites had a reaction with galvanized sheetmetal and to prevent this reaction, it was necessary to paint all galvanized sheetmetal surfaces in contact with the bentonite suspension.

Fenwick said in one instance a model study had been made with dried oat grains used to simulate sediment material.

Martin asked about experiences with model studies simulating bed loads composed of larger sizes.

Gildea said he had used sand to represent larger sizes of bed load and had made no attempt to simulate the size analysis of prototype materials, but had merely tried to get movement of the bed material.

Fenwick said the Corps had used haydite, but had found the density of individual grains to be inconsistent.

Martin stated that the American Aggregate Company of Chicago was able to supply all types of aggregates and Iowa University was obtaining aggregates from Chicago at about the same price we were obtaining local material.

Carlson stated that the sand used in a number of Bureau of Reclamation model studies is from a local sandstone deposit. Passing it through a hammer mill results in a uniform sand of approximately 0.2-mm diameter. He said the plastic being used to represent suspended sediments had been obtained from Dow Chemical Company and passed through a hammer mill until the desired gradation had been obtained. He then asked what systems were being used for measuring sediment concentration.

Fenwick indicated most of the Corps' studies were concerned largely with configuration of the bed, and sediment concentrations were not of primary importance. He said tidal models pose a different problem, as sediment on the bottom may be moving upstream when a surface flow is downstream. He stated that gilsonite with a specific gravity of 1.03 to 1.05 was widely used to represent sediments in tidal models, but when gilsonite was used, it had to be injected wet and it should not be allowed to dry. He stated that on occasion, deposited gilsonite had been removed from the model bed and weighed to determine the amount of material that would deposit in a given area. He indicated a little disturbance will place the gilsonite in suspension and it may work well for suspended sediment studies. He remembered model studies in which pine resin was used to represent the sediment, but results had not been satisfactory.

Fairchild stated that the Beach Erosion Board had conducted wave studies with water temperatures at 50° and 80° F, and more suspended sediment had been found in the colder water and a faster rate of change of bed profile occurred with cold water. It is believed this was due to the viscosity change.

<u>Use of Radioisotopes in Sediment Studies</u>

Fortson started the discussion by describing a planned study of the Corps of Engineers. The study will be similar to one conducted in San Francisco Bay in which radioactive tracers were used to trace bed sediment movements. The study will be in Galveston Bay to determine if tidal and wave action brings sand materials into certain areas or if the material is coming from other sources. There have been some difficulties in organizing this study. Scandium with a half-life of 85 days is being considered for use. The material must be radiated at Oak Ridge, and they do not like to use sodium sand as it becomes too hot. Oak Ridge prefers quartz sand, and a sand fused into glass beads and tagged with gold is to be used in the study. Some of the difficulties encountered in the study are: (1) obtaining the license, (2) having public relations meetings, (3) meeting safety engineers' requirements, (4) clearing with the Surgeon General of the Army and the AEC, (5) fusing and grinding the glass, (6) obtaining the correct type of containers for the material, and (7) storage and handling of the material. After all these difficulties have been overcome, the Corps plans to place the material on the weather side of a jetty and trace its movements by dragging a sled containing monitoring equipment along the bottom from a boat. In his opinion, the radioactive tracers would havea restricted use in the laboratory. However, a researcher from Northwestern University had visited the Corps laboratories and had used some radioactive material in a tidal model.

Florey stated that to obtain a license for use of radioactive material, you must state what type of material is to be used, what it is to be used for, where it is to be used, and numerous other data. He said that in all of the Bureau work, sealed sources are being used and as a result of this, less administrative details are necessary. He stated tritium is a heavy isotope of hydrogen and the water molecule containing the heavy hydrogen behaves chemically similar to ordinary water and would not be absorbed into the soil particles. He indicated some general use could be made of a material such as this; however, expensive monitoring equipment is necessary in its use.

Nelson asked about the possibility of using radiation methods for measuring size gradation or suspended or bed transport.

Florey suggested monitoring equipment may be used to measure radiation levels in various strata or that various particle sizes may be tagged with different isotopes and the different energy levels of radiation measured to help determine size gradation.

Campbell asked about using radioactive materials in a manner similar to salt injection methods where a float containing the radiation source could be used in the channel.

Florey stated a technique had been patented by Don Hull in which he uses a total count over a relatively long period of time to determine discharges in a manner similar to salt velocity methods. For this method, he uses low concentrations of radioactive materials and claims good accuracy. The big difference between the salt velocity method and the method patented by Mr. Hull in the "Hull Method" the counter may be placed outside of the water flow area with no resulting disturbance of the flow.

Fortson indicated the costs of the radioactive materials for the study by the Corps are insignificant.

Douma said an investigation had been conducted regarding the cost of studying sediment movements of a shoal, in New York harbor. The first estimate which had been made by a consultant was \$10,000. However, after a 6-month period of more detailed consideration of the work involved, this estimate had climbed to \$86,000.

Elder stated that the Surface Water Branch of the USGS is using radioactive isotopes in East Tennessee and West Virginia to study turbulence in small creeks.

Thomas said the USGS has been attempting to determine distances necessary for radioactive contaminated waters to become safe through dilution, and work on this study had been conducted at both the Colorado State University at Fort Collins and the Rocky Mountain Laboratory, 2 or 3 years ago.

Fortson added that for activating the material to be used in Galveston Bay, it was necessary to provide aluminum containers no larger than 3-1/2 inches by 7 inches and the cost of activating was $90 per target.

Douma said the San Francisco Bay experiments with radioactive tracers had been successful. They were able to trace sand movement, and the San Francisco district had written a report covering methods used and results obtained.

Representing Sediment Transport in Intermittent Streams

The discussion was started by Gildea. He posed the question of how is equilibrium obtained and wondered if there are ever equilibrium conditions. He asked if models were stopped at a high stage to obtain bed conditions, or was some type of continuous recording made.

Fenwick said hydrographs of Corps' models are usually run in steps. Time scales may vary with stage, and at high stages more sediment will move than at low stages.

Carlson stated that in the jack and jetty model studies of the Bureau of Reclamation, the model was operated at various stages to show the effectiveness of the installation at these stages.

Martin pointed out the problems were complicated in the Middle Rio Grande Valley because flashfloods may occur and deposit large amounts of sediment in the main stem.

Carlson suggested the possibility of tagging materials with fluorescent paints or manufacturing fluorescent materials to be placed in models. He said this technique was being used in England and information regarding its use has been obtained by the Bureau. However, some difficulties are being encountered in obtaining the necessary chemical materials.

Murphy said a technique similar to this has been used in studying depth of scour around bridge piers.

INSTRUMENTATION, ANALOGS, AND DATA
PROCESSING SESSION
August 10, 1960
1:25 to 2:25 p.m.

Instrumentation for Prototype Measurements and Methods of Recording and Processing Data

The discussion was opened by Martin, who requested that Barbarossa present a plan of the Corps of Engineers' Division Office at Omaha, Nebraska, for large scale prototype tests of a hydroelectric installation to be made in conjunction with an unprecedented computer study which will give results for water hammer, surge tank effects, speed regulation, and governing stability in one package. Field test results will be used to check validity of computer predictions and to check operation in relation to design. Barbarossa stated first of all, his main interest in recording and processing data was from the viewpoint of an engineer. That is, he considered the whole ADP system a tool to obtain an end result. He added that it appeared a powerful digital-type data processing machine would have to be used on large problems such as the one he was about to present. However, the easily programed Burroughs E-102 computer can be used for smaller problems by engineers with a minimum of computer training.

Barbarossa used a large drawing for the purpose of presenting instrumentation plans for the prototype tests. The drawing was a sectional elevation view along a penstock center line of the Garrison Dam hydroelectric installation. Barbarossa stated one of their main concerns in regard to the Garrison tests was to obtain data that would be useful in evaluating losses in large pipe tee installations. The tremendous amount of data that will be acquired will be processed by automatic computing devices.

As demonstrated in his ASCE paper (HY 4, April, 1959), he said load rejection and full load demand studies can be made by use of an IBM 650 computer, based upon conventional procedures; but the procedures do not give conclusive results insofar as surge tank stability is concerned. Conventional manual procedures are based upon various assumptions, including: separation of the hydraulic system from the action of the turbine governors; no allowances for time delays in pressure-wave propagation; and others. The Massachusetts Institute of Technology has the contract of developing computational programs for the IBM 704 that will include all pertinent elements without the usual simplifications. MIT has worked for about a year, and about 2 more years will be required for completion of the study.

Various offices of the Corps of Engineers concerned have agreed on the prototype test installations for the Garrison system. A portion of the test equipment will be: (1) velocity probes through the penstock walls that will protrude about 2 feet into the flow from the wall with six pressure transducers in each probe to permit determination of velocity distributions; (2) a number of electric recorders; (3) pressure cells at all critical points of the hydraulic system; (4) velocity probes in a surge tank riser; and (5) strain gages and accelerometers where deemed necessary. All data obtained with the foregoing instrumentation will be obtained simultaneously with measurements of turbine and generator performance.

Barbarossa explained the electric recorders would possibly include photographic-type oscillographs, Brush direct writing recorders and magnetic tape recorders for pressure fluctuations at 28 points. Eighty-nine channels of data are to be recorded simultaneously with reference to a common time base and time intervals of 1/100 of a second. When the Garrison system test is completed and analyzed by automatic data processing machines, it will be the first time that a complete picture of transient conditions in an hydroelectric plant will be available.

Barbarossa stated they were concerned with how to obtain data that would reveal hydraulic conditions for unsteady flow through an orifice into and out of a surge tank. He stated the need for a systematic study of tee losses and hoped that this study might help produce some useful results.

Campbell indicated there was also a definite need to study tee losses without an orifice between the large pipe tee and a surge tank and also a nozzle between the tee and the surge tank.

Kuemmich asked what types of oscillographs they had in mind for recording data during the Garrison tests.

Barbarossa stated they were considering Brush recorders for low frequency phenomenon.

Colonel Lang stated the "Miller" equipment, used for blast recording, might be applicable for recording high frequency fluctuations of various hydraulic phenomena. Campbell indicated the "Miller" equipment is probably too fast for the type of data to be obtained.

Barbarossa stated that E. B. Pickett, Chief, Prototype Test Section, Waterways Experiment Station, is handling plans for test equipment and no one present was entirely familiar with the planned employment of electrical recorders.

Thomas asked if anyone present knew of a system that could be used to analyze the problem of pressure swings in penstocks and draft tubes which also produces power swings of generator output.

Barbarossa stated they plan to take data that will permit analysis of this problem. Also, it would be desirable to isolate the Garrison Dam

Powerplant from the main electrical distribution system during tests, because of system power fluctuations. He also stated that the plan of effectuating power load changes has not yet been completely worked out.

Martin asked Swain, Chief, Automatic Data Processing Branch, Bureau of Reclamation, what facilities we have that could possibly be used to analyze the type of test data Barbarossa has been explaining.

Swain explained that we do not have equipment to convert data recorded on magnetic tape to a state to be analyzed on our digital equipment.

Campbell said it should be possible to transfer data from magnetic tape to punch tape for digital analysis.

Colonel Lang stated that he had a thought on this problem that was not related to water resources; however, an instrument has been developed for the military that can be used to transfer oscillograph traces to punch cards. It is used on 8-channel oscillograph records from soils tests. He explained it was a machine on which a cursor is placed at a certain point on the oscillograph record and the operator could operate a foot pedal to transfer the x, y trace intelligence to punch cards. It is a Telecomputing Corporation Contact Reader 099.

Barbarossa said they have encountered the problem of having test data on magnetic tape which could not be put into digital form for machine analysis without considerable additional expense. MIT had tried to help with this problem, but to no avail.

Campbell was convinced data could be transferred from magnetic tape to perforated tape, then to punch cards, but said each step sacrifices some accuracy. He said that Mr. Hanes at WES had designed such a digitizer which was now under contract.

The test of the Garrison hydroelectric system is to be performed about next April or May, according to Barbarossa, and any representatives of the Bureau of Reclamation would certainly be welcome to witness the test.

Martin stated that at the present time, we are concerned with processing data from steady state tests. He asked Schuster to describe the processing of data from canal capacity tests.

Schuster explained the material he had was a continuation of Thomas' description of the problem of inadequate capacity of large canals. Vertical velocity distribution measuremements have been taken at equally spaced distances across large canals with Type A current meters. We have a maximum of eight velocity values for each vertical profile and are attempting to define shear at the canal boundary according to the Karman-Prandtl logarithmic velocity relationship for rough boundaries. To do this, we have been using plots of the log Y/D versus V and simplify the equation to boundary shear = $C(V_2 - V_1)^2$. We are using these data in an attempt to develop plots of boundary shear distribution on the wetted perimeter of the canal. Preliminary shear distribution at the canal boundary has been obtained, but not finalized. We have turned over to the Automatic Data Processing Branch, the data analysis for computation of the shear distribution curves. If we discover the physical characteristics of canals change the boundary shear distribution, it may be possible to alter the typical canal trapezoidal shape to decrease shear losses. Also, if we can obtain a correlation of velocity distribution to Manning "n" values, it will eliminate the need for difficult head loss measurements during canal tests. Data processing machines are being used to analyze a grid system of canal velocities with respect to discharges. We still need to obtain data to determine shear values close to boundary surfaces. We are now interpolating to extend the data to the wall boundaries and a log distribution is the best way we now have. Schuster asked if anyone had suggestions that would help us obtain better data for computing shear values at or near the boundary surfaces.

Barbarossa asked if a Preston or shear tube might be used for this purpose.

Schuster stated that these tubes would possibly yield good results on very smooth surfaces, but not on rough surfaces such as we have in concrete-lined canals. Participants of the meeting were invited to observe samples of concrete canal lining in the Hydraulic Laboratory from the Columbia Basin Project. Schuster also stated we plan to use these samples in an air model for measurements of boundary shear.

Campbell remarked that MIT had used a Preston Tube for shear measurementsand had found a small reduction of shear at the intersection of the bottom and the side slope. The analysis of Olsen and Florey showed the shear to be zero at this point. Dr. Ippen had informed him that zero shear at the corners was a philosophical conclusion and has no practical basis.

Murphy asked what would be used as a basic reference line when measuring shear values on a rough surface.

Schuster stated we have literature references that will help determine how to use a Preston Tube if it is applicable.

Campbell asked if we were thinking of rounding the corners of the bottom of unlined trapezoidal canal sections. He stated that he knew of one canal where contractors were required to make sharp corners in their trapezoidal canals even though this adds little to the hydraulic efficiency.

Thomas stated the Bureau of Reclamation had relaxed specifications to allow rounding of the corners.

Martin asked Schuster to indicate the amount of work required to analyze data from the large canal capacity tests.

Schuster stated fifteen 8-hour days were required to perform calculations on data turned over to the Automatic Data Processing Branch. If this could be done by machine, it could possibly have been completed in 60 minutes. This work was for analysis of 34 vertical velocity profile measurements and the related preliminary shear values which comprises one complete set of data. We now have on hand 10 sets of data that have not yet been touched.

Martin asked Swain how the transient and steady state problems appeared to him with respect to machine analyses.

Swain said first, the engineers working with data have to be educated to make them realize the capabilities of the data processing machines. Similar programs for the Columbia Basin Project have been set up to transfer ditchriders' data to key punch cards so canal discharges can be machine computed. Also, a problem for the Soil Conservation Service involving 19 variables and 763 sets of observations were reduced in 8 hours on the IBM 650 machine.

Martin asked if any of the people present had small electrical computers in their offices.

Barbarossa said the Kansas City office of the Corps of Engineers has a small Burroughs computer in use 100 percent of the time (one shift). This machine is very easy for engineers to use with a minimum of training and after becoming experienced, engineers very often come up with larger problems that require a more sophisticated machine. He stated that the Kansas City District has authority to install an IBM 1620 system. This computer has the capability of working with variable word lengths. In many engineering problems, word lengths of 3 or 4 digits are adequate for computation purposes.

Enger stated most of our problems are not big enough to take to the IBM 650 machine and a small computer would be very useful in our own office.

Barbarossa agreed with this opinion.

Brownell stated they had a Burroughs E-102 computer in their hydromechanics laboratory, but it was used only approximately 50 percent of the time due to availability of other computers. He stated that the Navy brings in big problems, such as results of a shakedown cruise of a vessel from comparatively long-term studies, and they want the results in a short time. This requires the use of large, fast computers.

Therefore, the Navy has acquired two Univacs, an IBM 704, and other large machines. The David Taylor Model Basin has the use of some of the big machines 5 to 10 percent of the time. The model basin prefers digital-type recording of data for steady state problems and analog recording for fluctuating systems. The model basin has probably 2 to 2-1/2 million dollars invested in data reduction equipment. He added that the Sea Keeping Division of the Model Basin has recently justified a computer center for analysis of analog-type data in which a plot of the information sought is used to obtain the desired result. They use Flexowriters, etc., to record data for digitalization. They have found that a small Burroughs calculator is very useful and the rate of use has leveled off to about 50 percent of the time.

Martin asked how many engineers use the small Burroughs computer.

Brownell stated that about 5 percent of the engineers use the small computer, but there is a wide variation of use. He also stated that instrument design people find practically no use for the computer, but that scientific and test personnel do. Also, that all the large equipment is very expensive.

Campbell stated that some engineers at WES had wanted a small Burroughs computer in the Hydraulics Division rather than an IBM 650 which was purchased for more general use. He said that much of their work requires only a desk calculator. They had used the IBM for curve fitting problems, but generally too much work is involved for programing an unfamiliar problem for this machine. Also, the programing system changes so often that it is difficult to keep up with it.

Fortson stated that this feeling is general throughout the WES, and engineers like the small Burroughs E-101 computer.

Martin asked Elder if he had any comments.

Elder stated that TVA has an IBM 704 computer and a Royal McBee LGP-30. The LGP-30 machine is controlled directly by the Chief Engineer's office. This office has sponsored schooling of a large number of engineering employees relative to the programing of this machine. The IBM 704 is operated on a TVA-wide basis and a special staff of programers and operators is available.

Swain stated that various regional and project offices of the Bureau of Reclamation have computers of various capabilities. Some of these offices find that a small machine is soon inadequate and they need a larger one. When this situation occurs, a variable word length machine would be desirable.

Campbell asked Swain if Colorado State University wanted to sell their outmoded small computer. Mr. Swain replied that he did not know, but representatives of CSU came down to see what is required to install an IBM 650 machine.

Martin suggested that the discussion be closed for a 15-minute recess. The time was 2:25 p.m.

SPECIAL TESTS AND SUMMARY SESSION
August 10, 1960
2:40 to 3:45 p.m.

A portion of the 12:30 to 2 p.m. discussion on ultrasonic devices and hydrophones was continued during this session. Upon questioning by Martin, Brownell stated that hydrophones are used extensively by the acoustic division of the DTMB. They are used for detection of cavitation noises, hydrodynamic noises in application of sonar devices and for water tunnel studies.

Martin asked if they are effective in detecting cavitation in hydraulic machinery and could they be reasonably used in laboratory work.

Brownell replied in the affirmative.

The size of the equipment was requested by Ball and Brownell recalled they were approximately 2 inches in diameter but smaller equipment might be available. He suggested that the laboratory could probably obtain this information upon request to the model basin.

Special Tests Performed by Participating Laboratories--Wave Studies, Seepage, and Seepage Control

A design of the prototype test facilities at Detroit Dam on the North Santiem River, 25 miles from Portland, Oregon, described by Webster, opened the discussion on special tests. This dam has been provided with two test facilities adaptable to many studies. One facility is a portion of the spillway chute to be used for study of air entrainment and bulking of the flow for comparison with model studies. The chute is 42 feet wide by approximately 400 feet long, and has rails on the sidewalls for an instrument carriage. This carriage can be equipped with instruments for determining the water surface profile along the chute. A discharge of 17,000 cubic feet per second can be provided under normal conditions with a maximum of 24,000 under special arrangement.

Electrodes have been provided in the sidewalls for velocity measurement. The salt velocity method is presently contemplated for this purpose.

An 8-foot-diameter pipe through the dam has been provided for closed conduit studies. Piezometers have been installed in an elbow and, after calibration, the elbow will be used for discharge measurement. In addition, provision has been made for the installation of an ultrasonic measurement device. Several studies utilizing the conduit are presently proposed, including a study of the Detroit-type slide gate on a 1:4 scale and the resistance of concrete to cavitation erosion.

According to Douma, the history of these facilities goes back many years. Many millions of dollars have been spent on research on small scale structures, and they realized that there was a pressing need for a large-scale test facility.

These facilities were first proposed for installation on the Pine Flat Dam, but later installed in the Detroit Dam because of a better water supply. The project is becoming quite active and test results should be forthcoming in the near future.

Martin asked Douma what had been the thinking on their approach to air entrainment or bulking problems.

Douma indicated that the salt velocity method of measurement would probably be included in the first investigations. Later, Straub's method of measuring air distribution would probably be included. With the velocity measurements, water surface profiles would also be determined. Douma referred to Thomas' measurements on Kittitas Wasteway as being background for present investigations.

Dexter inquired how the Corps justified the use of water for these studies.

Webster indicated there was no objection as long as an excess was available. This particular dam also has a reregulating dam for downstream storage and, at present, there is a surplus of power. In the future, these tests may require the purchase of water.

Campbell said that at the time of the Denison Conduit tests, the Office, Chief of Engineers, had arranged to reserve the necessary quantity of water to conduct the tests. Such an arrangement was also made for the Fort Randall prototype tests. It had been reasoned that the value of the test data exceeded the value of the power.

Martin inquired of the nature of ultrasonic measuring devices in the 8-foot pipe. Final design of this device has not been completed according to Douma, and Campbell indicated the device would follow the design proposed by Swengel and Hess. This design consists of wall transducers working through a sonic metal window diagonally across the section. They hope to improve on the lower velocity range; that is, increase the accuracy for flow velocities less than 10 feet per second.

Past use of this equipment at the Safe Harbor Powerplant has indicated a $\pm$ 1 percent accuracy for velocities of 15 to 18 feet per second.

It is believed that in larger conduits where velocities may range to 70 feet per second, even better accuracy may result. Phase meter accuracy has improved greatly in recent years and use of this equipment has assisted in producing a high order of accuracy in velocity measurement.

In answer to a question on the effect of sediment, trash and air on the velocity of sound in water, Campbell indicated that the Swengel and Hess study showed no appreciable effect with small concentrations.

Brownell reported that the St. Anthony Falls Hydraulic Laboratory is developing an instrument to detect the change of sound velocity in air-filled water.

Following this line of thought on velocity measurement, Campbell asked how an electromagnetic flow meter developed by the Navy might be obtained for study for application to laboratory and prototype measurements.

Thomas briefly described the instrument that was studied by the Bureau's Hydraulic Laboratory and the development work that is in progress under a Geological Survey contract.

Martin asked Elder if he wished to describe any instruments they were using for prototype measurements.

Elder discussed the problems involved in the study of the big ship locks where it is difficult to get good model-prototype similarity. They are approaching the problem by a very careful study of the Wilson Lock model and are extending the tests to the prototype. To date, the model's average pressures scale up to the prototype's average pressures. Prototype fluctuations were not, in general, predicted by the model. Considerable work remains to be done on scale ratios for frequency and amplitude measurements. Results have not been conclusive to the present.

Thomas directed a question to Barbarossa, asking if piezometer and manometers were to be used in the Garrison test for steady flow and transducers for transient flow. It was indicated that transducers will be used for steady state conditions as well as for transient conditions, and it was stated that approximately 3 weeks will be required for installation of the Garrison test equipment.

Martin then asked Fairchild if the Beach Erosion Board had made prototype measurements that might be related to our general laboratory or field studies.

Fairchild described an equilibrium profile beach study in a wave tank 600 feet long, 15 feet wide, and 20 feet deep. As indicated by a sketch on the chalkboard, model wave tests (1:10 scale) using a sand beach produced accretion but a directly opposite effect, that of erosion, was produced on the prototype beach. The effect was identified with the fact that the same sand size (M_{do}=0.22mm) was used in both the model (1:10 scale) and the prototype. Test results of model beaches using coal of the same size as sand, but lower specific gravity (1.5) scaled on a settling velocity basis, gives promise of explaining the diverse beach adjustments found where the same size sand was used in both the model and the prototype tests.

Thomas described the ultrasonic velocity gaging station at F or H Street in Sacramento, California. This was particularly directed to Gildea, who said he would check on the progress of this installation.

Campbell asked how the cross section was determined for computing the discharge.

Thomas explained the installation was in a leveed section of the river and thus the cross section would remain relatively constant.

Campbell noted for further information that Batchelder of Raytheon had done development work on an ultrasonic device based on shifting frequency to hold phase shift constant.

Martin asked that Thomas give a brief explanation of the Bureau's work and the use of the electrologging device for tracing seepage flow from canals.

Since our first contact had been through Turner of Phoenix, Arizona, Thomas described this method as using two channels of resistivity measurement only. This method, at present, is in the development stage and proposes to quickly survey a canal while in operation to find where the canal is leaking. Since both a self-potential and a change of resistance exist and are caused by flowing water, the Bureau's equipment measures both self-potential and resistance.

Because of the preliminary nature of our studies, the results are not conclusive to date. Although the devices are sensitive, the records require a great deal of interpretation.

Martin, in summarizing, remarked that this being a new technique in the irrigation field, it may have wider application than presently envisioned.

This concluded discussions at the meeting on Hydraulic Laboratory techniques.

In closing the meeting, Douma stated that he felt that the meeting had been very successful, but he noted there had been a general conflict between the discussion of the design problems and the laboratory techniques. He wondered if possibly the meeting might be expanded with regard to time, to allow for a discussion of both design and laboratory technique problems. He suggested that consideration be given during the research coordination meeting in the spring of 1961 to having a third meeting of this nature and extend the time to two 2-day meetings with one period devoted to design and one to techniques.

Campbell, in adding to Douma's remarks, suggested that we stress research for design purposes and what is needed by the designers in both the Corps and the Bureau to prevent duplication of effort. He expressed the belief that our learning is more rapid by the exchange of ideas such as occurred during this present meeting.

Brownell extended to the group an invitation to visit the DTMB.

Douma, in turn, suggested that the group might hold its next meeting in Washington at the Beach Erosion Board, or the David Taylor Model Basin.

Brownell could not offer an invitation to the model basin, but indicated the idea justified additional thought, especially for a meeting at the Beach Erosion Board with a visit to the David Taylor Model Basin.

The meeting adjourned.

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