Proposal to

NATIONAL SCIENCE FOUNDATION

for

FLUID MECHANICS RESEARCH LABORATORY FACILITIES

COLORADO AGRICULTURAL AND MECHANICAL COLLEGE
Fort Collins, Colorado

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COLORADO AGRICULTURAL AND MECHANICAL COLLEGE
FORT COLLINS, COLORADO

OFFICE OF THE PRESIDENT

February 26, 1957

Director
Mathematical, Physical and Engineering
Sciences Division
National Science Foundation
Washington, D. C.

Dear Sir:

Transmitted herewith is a request for assistance from the National Science Foundation to develop a much-needed program in hydraulics research. This request includes a plan for providing the necessary basic equipment and facilities, and a plan for supporting fundamental research efforts in the fluid mechanics field. Under this plan the required facilities would be completed in 8 years, and a 10-year program of research would be provided.

While tentative building plans have been proposed, these must be regarded as preliminary. Detailed development of plans will be under the supervision of the College Architect. The College Engineer will be responsible for supervising construction. Technical responsibility for operation of the facility will be assigned to the Head of Civil Engineering.

Colorado A and M College has a long history of research effort in the fluid mechanics field. The nucleus of staff and facilities has already been built. These are inadequate, however, to meet the needs of our expanding economy for research related to water. In the face of a greatly increased educational load, Colorado is not in a position to finance these needs. Moreover, this program will serve the region and the nation generally as much or more than merely Colorado. Major industrial support is also unlikely, perhaps because water developments are usually the concern of the public rather than of private industry -- as is the case with much engineering research.

I believe the proposed program to be an extremely vital one. I also believe that it can be conducted at Colorado A and M College perhaps more effectively than at any other location. I strongly urge, therefore, that every possible consideration be given to the attached proposal.

You should be informed that, by recent legislation, the name of this institution has been changed from Colorado Agricultural and Mechanical College to Colorado State University. This change will become effective on May 1, 1957. Beginning on that date, negotiations will be conducted under the latter name.

Sincerely,

W. E. Morgan

W. E. Morgan
President

WEM/rms

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FIGURES

Fig.

INTRODUCTION

For almost three-quarters of a century Colorado Agricultural and Mechanical College has studied conservation of water as it relates to arid or semi-arid lands. An increased accent must be placed on these studies today because of a certainty of greatly increased pressure of population upon the water resource and its related resources; and because the storehouse of fundamental information on which hydraulic science and engineering is based is becoming depleted. These are the reasons why this request for assistance in developing the necessary tools to conduct vital research in these fields is being made to the National Science Foundation.

Hydrology, in its broadest sense, embraces the complete understanding of water -- its basic nature, its occurrence, its movement and its use. The search for improved knowledge of water in all of its aspects needs to be accelerated; at Colorado Agricultural and Mechanical College it is proposed that emphasis be placed on those aspects of hydrology most closely serving engineering, viz; the diversion, transportation and use of liquid water for irrigation, power production, domestic and industrial purposes; erosion and deposition of sediments by water; snow, especially as it relates to water supply; ground-water drainage; and evapo-transpiration. In all investigations the research would be to:

1. Try to achieve the best possible understanding of the fundamental processes involved in the phenomenon, and
2. Determine how this understandingmmay be extended to conservation of the resource on a practical basis.

Much of the need for the proposed research arises from problems endemic to the vast arid and semi-arid region extending from the longitude of Iowa to the Pacific Coast. These special problems arise primarily from the deficiency in precipitation that necessitates increased emphasis on water conservation; but secondarily from soil, topographic and geographic, and climatic factors other than precipitation. These special conditions call for much specialized research, as well as specialized knowledge and understanding on the part of the men who must meet them. At the same time, nevertheless, much of the fundamental research and understanding necessary is of common interest to everyone who deals with water, regardless of location.

Inseparable from research at a university is education -- an objective of primary importance to Colorado A and M College and of vital interest to both the region and the nation. Personnel having a particular education capable of dealing with problems related to water are needed in this and other similar areas.

Established practice at Colorado A and M College, as at most land-grant universities, is to work co-operatively with other agencies, usually federal and state, having common interests and problems. In these relationships the facilities of the institution are made available to designated federal and state technicians. The free exchange of ideas is promoted.

In other cases the university may undertake to assist federal and government agencies with their problems on a research contract basis. Such pooling of resources, both physical and intellectual, results in an increased potential of capability and greater economy of funds and time. Availability of an adequate facility with a capable staff in hydraulics and fluid mechanics is important to these agencies in their routine assignments and to the over-all national security as well.

Significant contributions to the program of assistance to under-developed countries could be made by the facility proposed herein. Significantly, many of these countries are located in arid or semi-arid regions. Water resource development is a primary step to be taken in all of them. These countries would be helped indirectly by technical progress made possible; and directly, by education of their personnel and exchange of staff.

Rather ideal conditions exist at Colorado A and M College for the development of laboratories in the hydraulics field. There is already in existence a core of such facilities and a research staff of considerable capability and maturity. Space on the campus is available for the necessary expansion. The geographical location is near the center of North America's sub-humid area. It is contiguous to both the Inter-montaine province and the Great Plains province, which are the two major geographic and climatic divisions of the arid west. The area immediately surrounding the institution is one in which water supply development and use for irrigation, industry, and municipal purposes under restricted supply is a mature art.

Most hydraulic research facilities are located in areas, especially along sea coasts, which would be relatively vulnerable in the event of war. This is not true of the Fort Collins location, which is quite far removed from high priority industrial targets. Research and development in hydromechanics is an important part of the defense program so that some dispersion of appropriate facilities into areas of low enemy target priority would appear desirable.

Local water supply is adequate for all laboratory purposes. The proposed development utilizes recirculating water initially obtained from City of Fort Collins supplies; however, direct water supplies could be developed, through irrigation distribution systems, from the Cache la Poudre River and from Horsetooth Reservoir, the terminal storage facility of the Colorado-Big Thompson Project. The latter source promises the possibility of providing a large volume of high pressure water for an annex to the laboratory. This annex would be located approximately one mile west of the campus.

This statement is presented in justification of a request by Colorado A and M College for support in developing its fluid mechanics research facilities. It includes a description of existing facilities and of research conducted to date. Research since 1948 is described in more detail. A future program of research is presented, followed by a general statement of plans for the necessary facilities and estimates of cost. The qualifications of the current staff are covered and a list of recent reports and publications is included. Research in hydraulics and fluid mechanics is conducted by the Civil Engineering Department of the School of Engineering.

FIG. I AREA SERVED BY COLORADO A & M FLUID MECHANICS RESEARCH

I

BRIEF HISTORY OF HYDRAULIC RESEARCH TO 1948

Instruction in engineering began at Colorado A and M College in 1880. Irrigation engineering was under the direction of Dr. Elwood Mead, who later was the first U. S. Commissioner of Reclamation. Experimental research in irrigation and hydraulics was begun in 1885. By the turn of the century important work on water measurement, seepage, duty of irrigation water, and artesian wells had been published. A paper on Forests and Snow published in 1901 reports what is believed to be the earliest effort to utilize snow surveys for predicting run-off. Early investigators included Dr. Mead, Prof. L. G. Carpenter and V. M. Cone. Climatology studies were started at this time and routine weather observations have been taken without interruption since 1887.

Construction of the Hydraulics Laboratory was begun in 1911. Significant research was accomplished on measuring devices, dividers, evaporation, seepage, wells, consumptive use of water by crops, streamflow forecasting, and sediment excluders. Outstanding investigators included Ralph L. Parshall, Carl Rohwer, and W. E. Code. In 1919 an outdoor laboratory was constructed on the Cache la Poudre River five miles northwest of the campus. Flows of up to 100 cfs are available at this site. In the early 1930's the size of the indoor laboratory was increased to 12,000 sq ft in order to accommodate the hydraulics laboratory work of the U. S. Bureau of Reclamation. Under the direction of E. W. Lane and J. E. Warnock, hydraulic models were made of Hoover

Dam, Grand Coulee Dam, Norris Dam, Wheeler Dam, and a number of other large dams. In 1940 the Bureau of Reclamation moved their laboratories to Denver and, with the advent of World War II soon after this, little was accomplished until the resurgence of hydraulic research following the war. Beginning in 1948, a program of research was started. This program has been financed in large part by outside sponsorship, through the Colorado A and M Research Foundation, but also by the Colorado Agricultural Experiment Station, and by co-operative work with the Agricultural Research Service and the Geological Survey. Since 1948 the hydraulics laboratory area has been increased by approximately 9,000 sq ft. Additional building space used to house the wind tunnels and containing an area of 9,600 sq ft has been procured and allocated to fluid mechanics studies involving air and water. An outdoor wave basin, in which models can be towed obliquely to a wave front, has been developed. These facilities are now served by fully equipped shops.

II

HYDRAULIC RESEARCH ACTIVITIES SINCE 1948

The research activities in hydraulics and fluid mechanics at Colorado A and M College may be divided into four interrelated categories. These are: (A) General Hydraulics, (B) Wind Tunnel Studies, (C) Wave Basin Studies, and (D) Miscellaneous. Presentation of activities since 1948 follows this division.

A. General Hydraulics

In 1948 an investigation was initiated which formed the basis for a number of later studies. This was an investigation to develop a method for the measurement of the total sediment load in the Middle Loup River, an alluvial, sand hill stream in north central Nebraska. Consideration of sampling procedures led to a decision to measure the total sediment load by means of standard suspended sediment sampling equipment. Thus the sediment travelling as bed load along the bottom had to be thrown into suspension. This was accomplished by installing a system of baffle plates to create the necessary turbulence. The resulting structure, developed in the laboratory, was installed in the Middle Loup River and has operated satisfactorily.

The above turbulence flume investigation led to studies of artificial and natural roughness in alluvial channels, transport of sediment in alluvial channels, and the sampling efficiency of standard techniques for sampling suspended load.

Also initiated in 1948 were extensive model studies of three dams; Bhakra, Hirakud and Rihand, to be constructed in India. These studies were conducted for the International Engineering Company, designers for the Indian government.

The work conducted since 1948 can be classified broadly as research on flow in open channels, research on hydraulic structures, and miscellaneous.

Flow in Open Channels

Channel roughness:- Stimulated by the turbulence flume experiments, two studies have been made of the use of baffle plates as a standard artificial roughness to simulate the roughness which occurs because of sand dunes in the bed of a channel. This type of roughness has been found to be more closely related to the natural roughness in an alluvial channel than the Nikuradse type, which is the standard for flow in closed conduits.

Investigations of resistance to flow in open channels are now being conducted on a co-operative basis at the Rocky Mountain Hydraulics Laboratory, Allenspark, Colorado. Here a 400-ft long sloping flume is used. This project is financed by a grant from the National Science Foundation. The distribution of shear in open channels has been studied under a J. Waldo Smith fellowship grant. This is important in order to apply the tractive force theory of stable channels. A study of natural roughness using gravel from one inch in diameter to four inches in diameter was conducted in a rigid-bed sloping flume, also under a J. Waldo Smith fellowship grant.

A small study on backwater effects resulting from bridge piers and abutments in open-channels was initiated in 1949. Beginning in 1955, under the sponsorship of the Bureau of Public Roads, extensive investigations were made using a sloping flume. Generalized solutions for use in design have been prepared for the case of a rigid bed. Studies are being continued for the alluvial bed. Scour around bridge piers and abutments, as well as the backwater created, will be studied.

Alluvial channel research:- Under the sponsorship of the Corps of Engineers, Barton and Lin conducted an investigation of roughness and sediment transport in an alluvial channel for different discharges and slopes. This study was made in an 8-ft variable slope flume in which a bed of fine sand was placed. Sediment as well as water was recirculated under equilibrium conditions. As a part of this study, an analysis of the sampling efficiency of suspended sediment sampling methods was made.

A theoretical analysis on the design of stable channels was conducted by Yu. This analysis was based upon the assumption that a particle on the bank or bed of a stream must be in stable equilibrium against the shear forces and the gravitational forces acting on it. Using a boundary layer theory approach, Ali made an analysis of sediment concentration in alluvial channels. Recently the National Science Foundation made a grant to Liu to conduct an analytical study of alluvial channel roughness.

An extensive field investigation of flow in stable canals in alluvial material has been made. This work was sponsored by the

Geological Survey, the Bureau of Reclamation, and the Corps of Engineers. Eighteen canals were studied in detail. An analysis was made of the distribution of the suspended sediment. The data are being studied in order to correlate the various theories relating to the design of stable channels.

A study of the development of meanders in an alluvial valley was conducted in the 8-ft wide tilting flume using a sand bed. Resulting data showed that the meander belt reached a stable width which was found to increase with discharge and slope.

An extensive investigation has recently been initiated as an extension of the study by Barton and Lin of roughness in alluvial channels. The length of the 8-ft variable slope flume has been increased to 160 ft for this investigation, which is sponsored by the U. S. Geological Survey.

In an effort to isolate the variables involved in the mechanics of sediment transport, an investigation was made in 1951 under the sponsorship of the U. S. Bureau of Reclamation. A turbulence tank designed so that uniform distribution of turbulence could be maintained from the bed to the surface of the water was employed. The principal objectives of this research were to determine the influence of temperature, particle shape, and turbulence upon the fall velocity and concentration of sedimentary particles. Recently a second study was completed using a turbulence tank. This study includes also the influence of wash load upon the concentration of bed material load.

A series of investigations were conducted by Corey, Wilde, and Schulz to determine the influence of shape of sand and gravel particles upon fall velocity in quiet water.

Hydraulic Structures Research

Spillways:- In an effort to determine the characteristics of flow over standard ogee spillways, Koloseus investigated spillway crests at various discharges other than design discharge. He also studied the influence of downstream submergence upon the flow over the crest. Thorson investigated the shape of the underside of the nappe, with various negative pressures under the nappe, in an effort to determine the shape of spillways which should be used for a particular predetermined negative pressure. This design of spillway crests is proposed as a means of increasing the discharge efficiency.

Stilling basins and drop structures:- A series of model investigations has been conducted with the objective of studying scour below jets. The first study was made by Doddiah in 1949. He investigated the scour which takes place owing to a vertical jet impinging on an alluvial sand bed. Thomas studied two-dimensional jets resulting from an uncontracted free overfall. His investigation included the influence of standard deviation of the size distribution of the bed material. Hallmark, extending Thomas' work, investigated the effectiveness of graded gravel riprap.

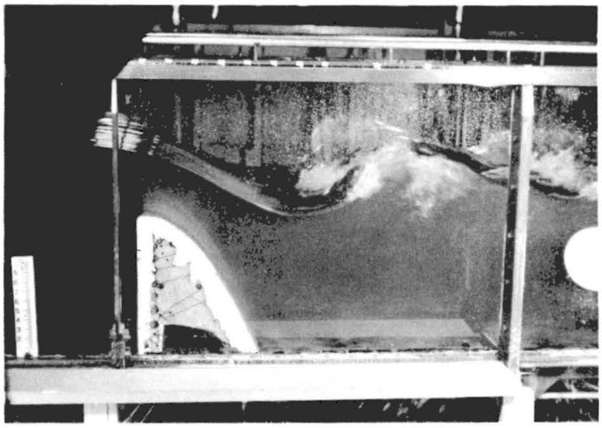
Recently the Agricultural Research Service and the Bureau of Public Roads have sponsored, on an extensive scale, an investigation to control scour at the base of overhanging culverts. The objective of these studies is to develop low cost stilling basins which utilize a standard scour hole, appropriate for the discharge, lined with graded gravel riprap to prevent scour.

Wiede made an investigation of the influence of floor blocks in creating a hydraulic jump for stilling basins using horizontal dissipation of energy.

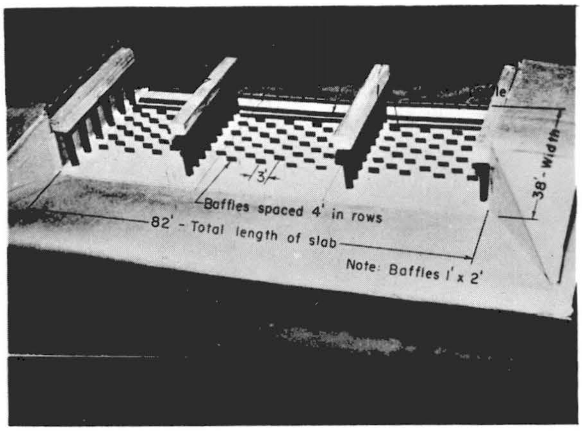
A manifold diffuser was developed. In this structure the stream is diffused into jets directed upward, which is an efficient means of dissipating energy. The structure was first designed and tested in a model, and then constructed in the field. Because of its satisfactory operation and promise of economy a systematic and generalized investigation is now being conducted to determine detailed design criteria.

Based upon the information from the scour studies in the laboratory, several drop structures were constructed in a reach of an irrigation canal near Fort Collins. A detailed field investigation has been made of these structures during two years of operation.

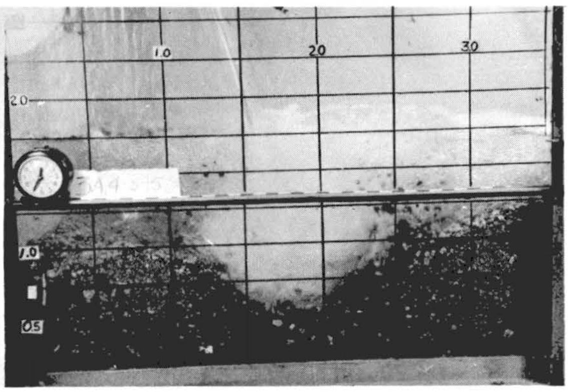
Measuring devices:- Several new devices for measuring water in canals, natural streams, and closed conduits have been developed. These include a pendant-vane deflector type of meter for open channel flow; a turbine-type meter for integrating the flow through an orifice; and a non-clogging modified Venturi flume for measuring discharge of steep mountain streams. Rating curves for very small Parshall flumes, below 3-in. width, have been prepared.



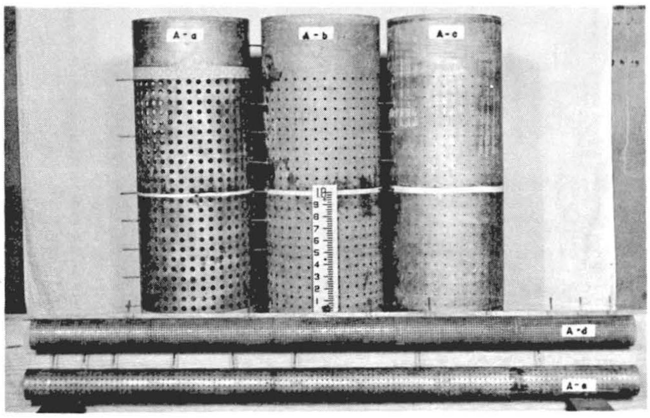
Model study of flow over the crest of concrete dams.



Model of turbulence flume installed on Middle Loup River, Nebraska.



Study of gravel riprap for drop structures.



Investigation of well screen performance.

Fig. 2 Photographs of Typical Hydraulic Research.

Miscellaneous

Conical diffuser:- Cermak conducted an investigation of the head loss in conical diffusers as expansions in circular pipes.

Sediment transport in pipes:- Under the sponsorship of Armco Drainage and Metal Products, the Research Corporation, and Tau Beta Pi Association, an investigation has been carried on for several years on the transport of sediment in 12-in. pipes. The purpose of the investigation was to determine the influence of boundary form upon the sediment-carrying capacity of the pipe. Helical corrugated, standard corrugated, and smooth pipe were used.

Sand excluders:- In 1948 a model study was made of the vortex tube sand trap. An extensive study of this device was begun in 1956 using recirculating sediment and a sand bed in the 8-ft wide tilting flume.

B. Wind Tunnels

Wind tunnel research began at Colorado A and M College in 1949 with the construction of a low velocity, recirculating wind tunnel. This research facility was designed primarily for the purpose of studying turbulent boundary layer phenomena related to the diffusion of heat, mass, and momentum. The design provided test sections 6 ft x 6 ft or 9 ft x 9 ft sq with air speeds up to 35 ft/sec. Special provision was made to insure a low level of turbulence in the ambient air stream.

Under sponsorship of the Office of Naval Research, a study was conducted to determine how water evaporation rates from a plane, smooth, saturated surface are related to various flow characteristics. Other evaporation studies conducted during the five years under this sponsorship include a study of the effect of rim height above the ground and above the free water surface upon evaporation from a circular pan and an investigation to determine the effect of shape of surface upon evaporation rates for plane, smooth, saturated surfaces. A number of theoretical investigations of atmospheric diffusion and heat transfer were also made.

In 1952, under sponsorship of the Bureau of Ships, Navy Department, and the U. S. Geological Survey, a 1:2000 scale model of Lake Hefner was placed in the wind tunnel in an effort to model evaporation processes and wind structure. Analysis of the evaporation rates and neutral profiles of mean velocity indicated that similarity had been achieved for the model and the prototype, provided the model data were extrapolated to the prototype by use of the Reynolds analogy.

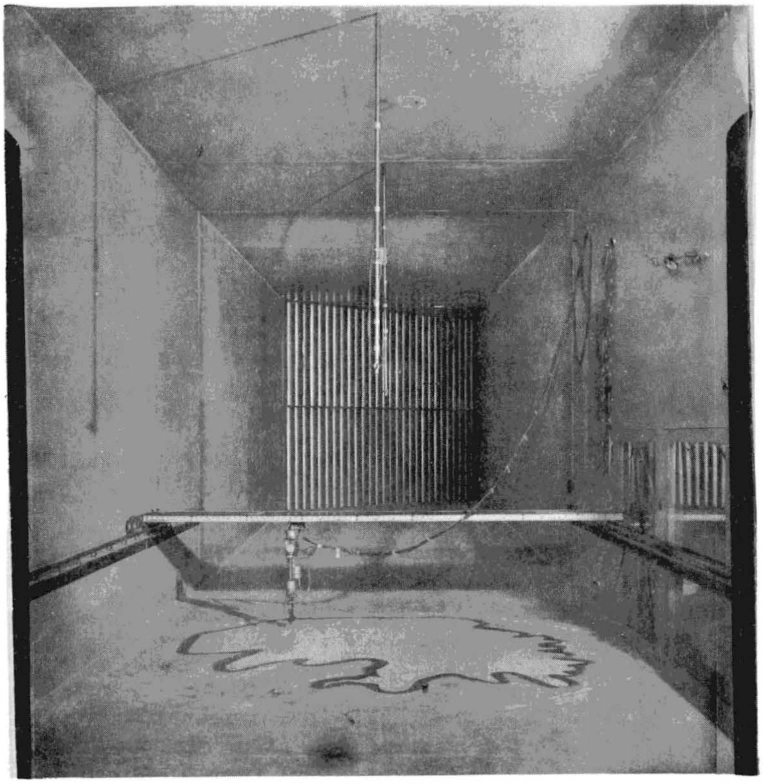
Wind chill measurements were made for the Quartermaster Corps using a uniform designed for use in the Artic and an electrically heated copper man. Heat loss measurements showed that, for a given uniform and a particular attitude of the model man, the heat loss coefficient was uniquely related to a form of Reynolds number composed of the ambient wind velocity and the mean diameter of the model.

The Air Force Cambridge Research Center has provided four years of support for a study to determine the effects of lapse rate upon the turbulent characteristics of a boundary layer formed over a plane, smooth, heated boundary. Comparison of the data obtained for mean velocity profiles and correlation coefficient profiles under lapse conditions shows that direct similarities exist for comparable data obtained from measurements in the atmospheric surface layer.

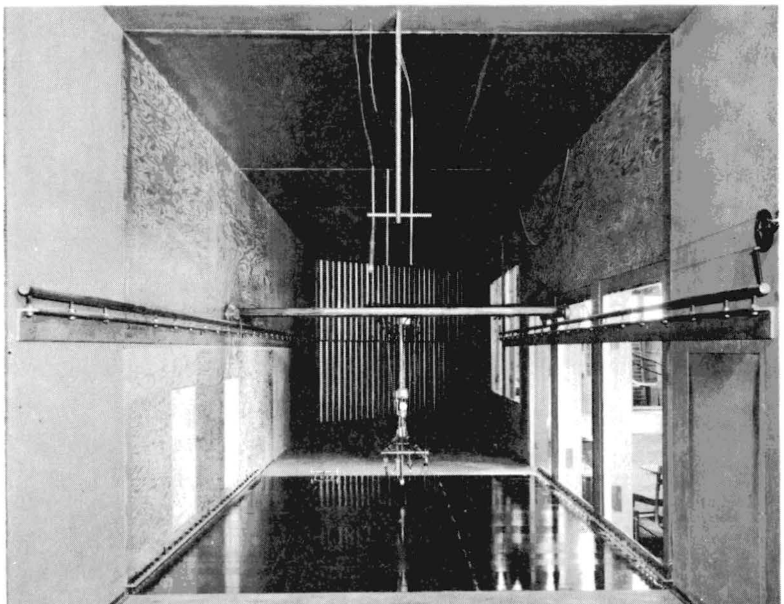
A study to determine the effect of atmospheric conditions, soil characteristics and water table depth on the rate of evaporation of water from soil surfaces has recently been initiated. This work is supported by the Colorado Agricultural Experiment Station.

Because of the apparent possibilities of modeling atmospheric surface layer diffusion phenomena in a wind tunnel, the Air Force Cambridge Research Center is now sponsoring construction of a new wind tunnel for this purpose. This wind tunnel is especially designed to provide a suitable turbulent boundary layer. Results obtained using the existing wind tunnel have shown these are necessary if the effects of thermal stability upon atmospheric surface layer characteristics are to be duplicated. The new wind tunnel has a 6-ft x 6-ft sq test section 80 ft long with a speed range of 0.5 to 100 ft/sec.

During the past eight years, sponsored research, costing approximately $250,000, has been conducted using the existing facilities. This support has permitted partial development of a unique wind tunnel facility and a group of scientific personnel which can do much toward bringing the sciences of fluid mechanics, thermodynamics, micrometeorology, and heat transfer together for the solution of many existing problems.



Model of Lake Hefner installed in floor of wind tunnel. Study of evaporation from the model was correlated with field measurements.



View inside test section. Study of effect on lapse rate on turbulent boundary layer characteristic. Painted circuit heaters on floor. Hot-wire instruments suspended from carriage.

Fig. 3 Photographs of Wind Tunnel Research.

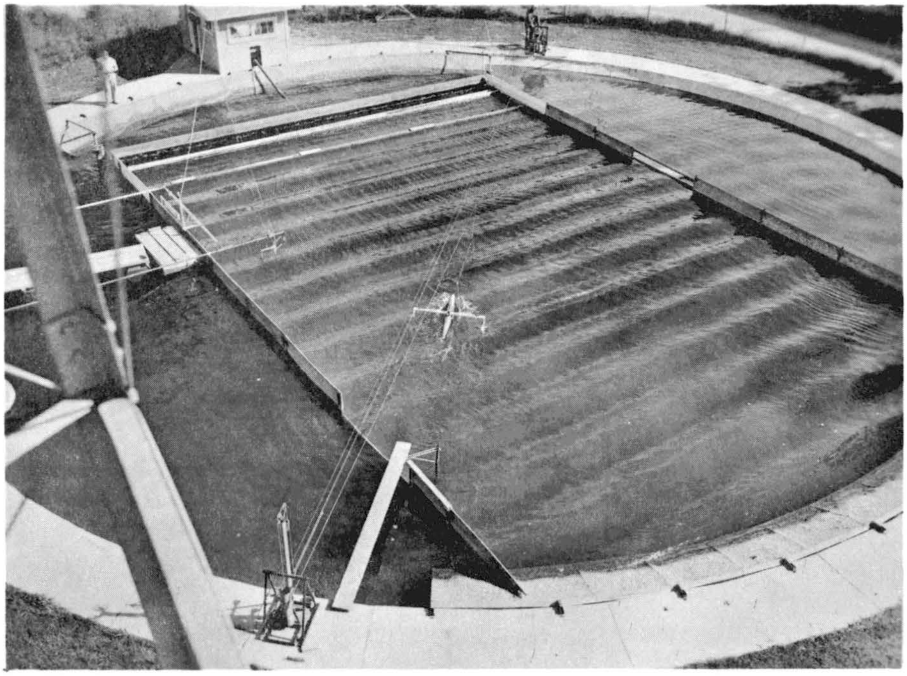
C. Wave Basin

The wave basin has been developed in an outdoor, circular reservoir 85 ft in diameter. The reservoir had been previously used for evaporation studies and for water supply storage for the laboratory.

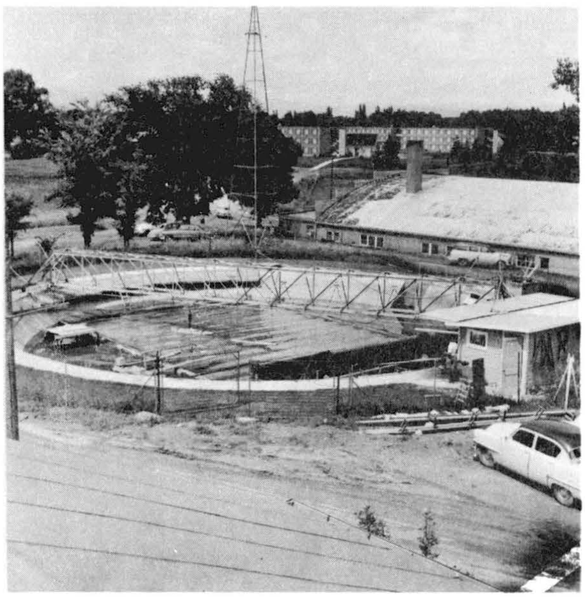
In 1952 a wave generator, wave guides, wave absorbers, towing equipment and associated instrumentation were constructed and installed in the reservoir under the sponsorship of the Navy Department. A towing bridge may be oriented so that the ship models may be towed at any heading relative to the wave travel. The relatively great depth (up to $6\frac{1}{2}$ ft) and the large width of the seaway (42 ft) are the unique features of this wave basin.

Several projects on the various aspects of seaworthiness of model ship and seaplane hulls have been conducted for the Navy Department. The motion of the model in response to the waves and certain essential forces are measured and recorded on multi-channel oscillographs. The electrical transducers used to provide the required electrical signals consist of precision potentiometers, strain gauge type dynamometers, pressure gauges, accelerometers, and wave probes.

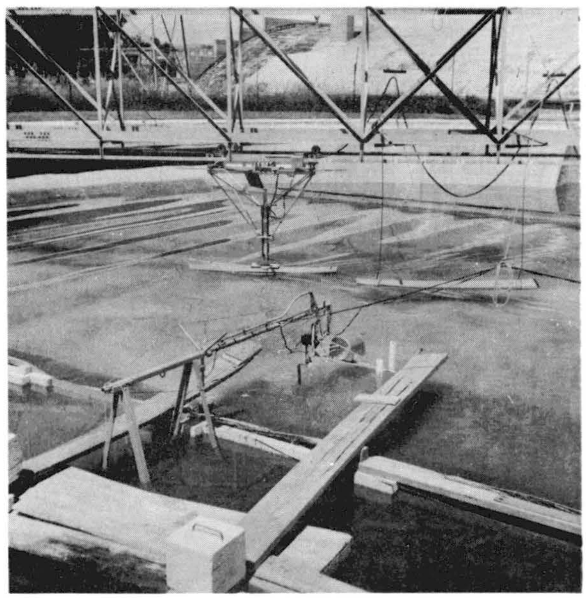
In the past four years of operation, the wave basin has provided support and valuable experience for both staff and students. Four different graduate students and twelve undergraduates have been employed on a part-time basis. Expansion and improvement of these facilities will provide more support for this educational activity. This will also permit fundamental research in fields other than those directly related to ships.



Model seaplane being towed at 135° with respect to direction of wave travel.



Ship model being towed by carriage traveling along towing bridge.



Ship model and its effects on the wave train. Wave probe in foreground.

Fig. 4 Photographs of Wave Basin Research.

D. Miscellaneous

General ground water inventory studies have been made throughout Colorado and these have been related to the development and use of water for irrigation. Contributions have been made which have led to improvement in well drilling and construction and well pumping plants. An extensive study has been made of the use of sprinklers for irrigation. Field studies have led to a new method of diagnosing drainage problems for irrigated lands and for predicting the irrigation potential as it is limited by drainage. A highly economical method of lining canals using water-transported suspensions of colloidal clay has been developed under a study sponsored by the Bureau of Reclamation, the Agricultural Research Service the Bentonite industry and various irrigation districts. Experimental installations have been made in Colorado, Nebraska and Wyoming and research is under way to evaluate these installations and to understand basic phenomena involved.

Under a co-operative agreement with the Colorado Agricultural Experiment Station and the Agricultural Research Service, and its predecessor the Soil Conservation Service, a series of research projects have been conducted on design and use of well screens and gravel packs in a well. J. E. Petersen and G. Corey conducted investigations of the affects of the well screen and Leatherwood and Halderman studied the influence of a gravel pack. These experiments were conducted using small models and a full-scale well model.

Keller made an investigation of tile interceptor drains for draining natural soil. This was a theoretical study supported by large-scale sand-model tests. Karaki conducted an investigation of the effect of depth to water table on seepage from a canal using a sand model. This was extended by Djanjigian using an electrical analog. Zee studied flow to a fully-penetrating gravity well using an electrical analog for flow and a membrane analogy for the free surface. Soliman, using the same technique, is extending these studies to the case of the partially-penetrating well. The problem of field measurement of seepage losses from canals was extensively studied and the results are presently being published. Under a similar arrangement the Soil Conservation Service has continued the development of streamflow forecasting using snow surveys. In 1948 Garstka made a special investigation of the seasonal water yield from mountain snow packs.

III

ANTICIPATED FUTURE RESEARCH ACTIVITIES

In sections I and II the research that has been completed or is in progress was discussed. In this section anticipated future research activities will be presented. These anticipated activities project the interests of the present staff and reflect the needs of the arid west in particular and the national welfare in general.

This section is divided into: (A) General Hydraulics, (B) Wind Tunnel Studies, (C) Wave Basin Studies, (D) Miscellaneous.

A. General Hydraulics

The future research activities in General Hydraulics at Colorado A and M College will be centered around improved water conservation and utilization and the design of structures to protect against the destructive action of water. Such objectives involve various aspects of upstream engineering, river control, water conveyance, use and management of water, canal regulation, and beach and harbor investigations. Emphasis will be placed on investigations which show greatest promise from the viewpoint of improved water conservation.

Problems arising in connection with the conveyance of water in open channels requires much improved and refined design. These problems are involved not only in river control and regulation but in conveyance of water using artificial channels as well. Certain fundamental studies are needed in order to improve these designs. These include basic open-channel-flow fluid mechanics, secondary circulation, flow around bends, and the characterization and effects of channel roughness. It is expected that all of these items will be given attention in the future at Colorado A and M College. The use of long variable-slope flumes in connection with these problems has been pioneered and promises to furnish an excellent means of attack both for non-erodible and erodible channels. There is also good opportunity for carrying these investigations to the field in the vicinity of the College.

Improved design must also include considerations of sediment mechanics from the viewpoint of scouring, sedimenting, and equilibrium conditions. Sediment mechanics is a very complicated science at best. A great many variables are involved. Therefore, it is necessary to attack the problem piece-meal. Basic relationships between a limited number of the variables, with the other variables omitted or controlled, must be understood in order to approach the over-all problem. Investigations in this field will constitute another important part of the proposed future research program. Included will be studies of sediment-transport equilibrium conditions in open channels, efficiency of various sampling techniques, relationship between ripple and dune formation and the resulting flow pattern and resistance to flow, turbulence tank studies of the influence of size gradation of sediment and the influence of wash load upon the total concentration and the distribution of a vertical section, and investigation of erosion and sediment transport problems connected with beaches and harbor installations.

Another aspect of open-channel water conveyance is the design of associated structures such as spillways, stilling basins, drops, checks, siphons, etc. These structures are costly; and better, less expensive structures are needed, both in artificial channels and in order to control erosion in natural channels. Improved fundamental understanding will be combined with laboratory testing to develop better methods and designs for these devices which need to be economical and yet effective. For instance, various techniques of energy dissipation and associated stilling basin designs will be given major attention.

The passing of water through, over, under, and around various types of dams involves a multitude of problems which continually need investigation. This is especially true for earth dams which are gaining in popularity because of their ease of construction and their low cost. Among the problems which will be investigated are spillways, chutes, stilling basins, arrangement of diversion works, gates, air entrainment, coffer dam construction techniques, tunnels, trash racks, fish ladders, and siphons.

Many aspects of the problems of handling water arising in connection with the multi-billion dollar highway program in the United States need investigation. The current study of alluvial problems associated with bridge piers and abutments should be expanded; gutters and roadside ditches should be studied in order to improve design and decrease maintenance costs; and better ways of handling surface drainage should be studied. One of the most important problems needing investigation is that of proper location of different types of culverts under a road crossing an alluvial channel. Frequently, the entrance to a culvert is plugged with sediment or the exit may be eroded until the culvert fails. Extensive study is needed to determine best entrance and exit conditions, grade, and alignment for greatest economy and best performance. Solutions of these problems in highway design may be extended to hydraulic engineering in other fields; for example, irrigation and soil conservation.

Many problems of upstream engineering and water application and use will be studied. Gully control, tillage practices to reduce sheet erosion, land management practices, effect of the soil bank program, drainage and methods of applying water to the land must be investigated if the farm lands are to be retained in a productive condition. Loss of even marginal lands cannot be allowed to proceed, as is evident when one considers that each year the population of the United States increases by 2,000,000 people, who must have food.

B. Wind Tunnel Studies

In general, development of the wind tunnel facilities will have as its purpose the treatment of micrometeorological and climatological problems from the point of view of fundamental fluid mechanics and thermodynamics. Micrometeorology will be approached by a study under controlled conditions of the characteristics of the atmospheric boundary layer, usually under forced convection. Account will be taken of the different conditions of mass, energy and momentum transfer related to thermal heating, surface roughness, evaporation, transport of sediment, topography, etc. In the field it is almost impossible to satisfactorily control or describe the many variables. Climatology will be approached in terms of its effects in agriculture, and to a lesser degree, industry. In agriculture, for example, water supply and conservation, and environmental effects on plants and animals will be studied. For industry, a study of gaseous waste disposal appears desirable. In order to make satisfactory quantitative progress in the foregoing fields a wind tunnel facility is necessary in which wind velocity, air temperature and air humidity can be controlled, and into which boundary layer characteristics such as scale and intensity of turbulence, temperature, and relative humidity may be introduced and measured.

Several rather specific research problems which may be studied with the aid of the proposed and existing facilities are as follows:

1. Determination of effects caused by strong heating or cooling from below upon the turbulence properties of a turbulent boundary layer formed over a smooth or a rough plane boundary.
2. Determination of flow fields near two- and three-dimensional bodies with a vertical dimension less than the turbulent boundary layer thickness when placed upon the surface of a plane boundary.
3. Measurement of two-point pressure correlations at the surface of a plane boundary over which a turbulent boundary layer having positive, negative or near vertical temperature gradients has formed.

4. Determination of effects upon mean velocity distribution in a turbulent boundary layer when flowing from a heated plane boundary to a cooled plane boundary, or vice versa.
5. Measure the diffusion coefficient for gases emitted from various types of sources into thick turbulent boundary layers with positive, negative or near vertical temperature gradients.
6. Develop techniques for modeling the atmospheric surface layer to study diffusion problems in cities and at industrial sites.
7. Determine the effect of vertical temperature gradients in the turbulent boundary layer upon the rate of evaporation from plane free water surfaces.
8. Study the effect of water table depth and soil and surface properties upon the rate of soil moisture loss by evaporation.
9. Determine methods by which mono-molecular films may be maintained on a free water surface to reduce evaporation rates.
10. Determine the nature of secondary circulations produced by air blowing over a body of water in which temperature gradients exist.
11. Measure the diffusion coefficients in a long tank filled with water when disturbances created by wind generated waves are present.

12. Determine the effect upon the flow resistance coefficient for wind blowing in the same or opposite direction of water flow in open channels of various shapes.
13. Study the effect of "wind stress" upon small animals at various air temperatures and relative humidities.
14. Determine the effects of air speed, temperature, and relative humidity upon the growth and transpiration of certain plants.
15. Determine the pressure distribution on buildings and the dynamic response of flexible structures when placed in a turbulent boundary layer having a thickness several times greater than the structure height.
16. Determine by model studies how to located snow fences and windbreaks to conserve soil moisture.

C. Wave Basin Studies

The future program of wave basin studies will include expansion of ship and seaplane studies, both from the point of view of the fundamental mechanics involved and from that of seaworthiness and performance of specific hull shapes. In addition to the ship and seaplane work, studies of value to other fields will be conducted. Among the specific studies which will probably be conducted are:

1. Protection of harbors and anchorages from tides and storm waves,

2. Wave action on waterfront structures, breakwaters and riprap facing,
3. Beach growth and depletion studies,
4. The mechanics of sedimentation under the action of waves,
5. The mechanics of sedimentation under the combination of currents and wave action, and
6. Model-prototype relationships of wave sedimentation problems.
7. Mechanics of virtual masses under wave action,
8. Water to air movement of missiles, and
9. Hydromechanics of the stochastic sea.

These studies have great potential use in the fields of Naval architecture, hydrodynamics, civil engineering, sanitation, geology, and oceanography.

The Colorado A and M College wave basin is believed to possess certain unique advantageous characteristics desirable for these studies. As an example, it now seems that the unusual circular plan of the wave basin lends itself to the generation of the stochastic sea; something which appears to be very difficult to do in the many rectangular wave basins now in existence.

D. Miscellaneous

Ground water remains one of the largest sources of undeveloped water supply in the West. Basic studies of the hydrodynamics of ground water will be continued. Studies designed to improve efficiency of utilization of ground-water supplies will also form an important part of future research at Colorado A and M College. Much research is needed on how to construct wells which are more efficient and have greater longevity. Improved pumps and pumping plants are desirable. An understanding of the origin of ground-water resources and of the mechanics of their depletion and replenishment is urgent. Means for utilizing aquifers now uneconomic because of low yields need to be developed. Part of the ground-water research program will be conducted in the field; however, there will have to be an extensive laboratory phase as well as theoretical investigations.

Most of the water falling in the Great Plains is lost to uneconomic evaporation. A thorough basic understanding of evaporation into the atmosphere is prerequisite to attacking the problem of moisture conservation. The soil conservation and evaporation studies, of great significance to this program, will be accelerated if possible. Understanding of fundamental principles involved in rainfall and drouth is necessary for economic use of arid and semi-arid lands. Field work in these areas will need to be supported by fundamental laboratory study.

A large proportion of the water diverted for irrigation in the western United States is lost by seepage from canals. In addition to loss of use of the water, this seepage causes water-logging and resulting salinity problems. The program of controlling these losses will therefore continue. Drainage of irrigated lands continues to be a major problem. Fundamental studies of processes involved in land drainage, as well as research in drainage engineering, will be continued.

Much of the research effort involved in reaching workable solutions in seepage control and drainage research will be conducted in the field. These field efforts, however, must be supported by a program of fundamental and applied research in the laboratory.

IV

GROWTH OF PHYSICAL PLANT

The rate of growth of hydraulics and fluid mechanics research facilities at Colorado A and M College has varied over the years owing to numerous factors, such as the two world wars, the depression of the 1930's, and use of the laboratories by the Bureau of Reclamation. This chapter will (A) briefly review the development of the facilities to date, (B) describe presently existing equipment, (C) mention the shop facilities, (D) discuss the library facilities on fluid mechanics, (E) describe the planned future development of facilities and (F) present a list of equipment needs.

A. Development of Facilities to Date

Research in fluid mechanics as applied to the problems of irrigation has been conducted at Colorado A and M College since its founding in 1879. The first course in irrigation engineering to be offered in the United States began in 1886.

Construction of the Hydraulics Laboratory began in 1911. The first laboratory consisted of a concrete-lined outdoor reservoir and three calibration tanks, a weir box, a 6-in. and a 12-in. pump used to return the water from the calibration tanks to the outdoor reservoir, and modest shop facilities. Fig. 5 is a photograph of the laboratory as it appeared in 1913. The next photograph, Fig. 6, is a small model of the laboratory showing the relation of the outdoor reservoir to the laboratory itself.

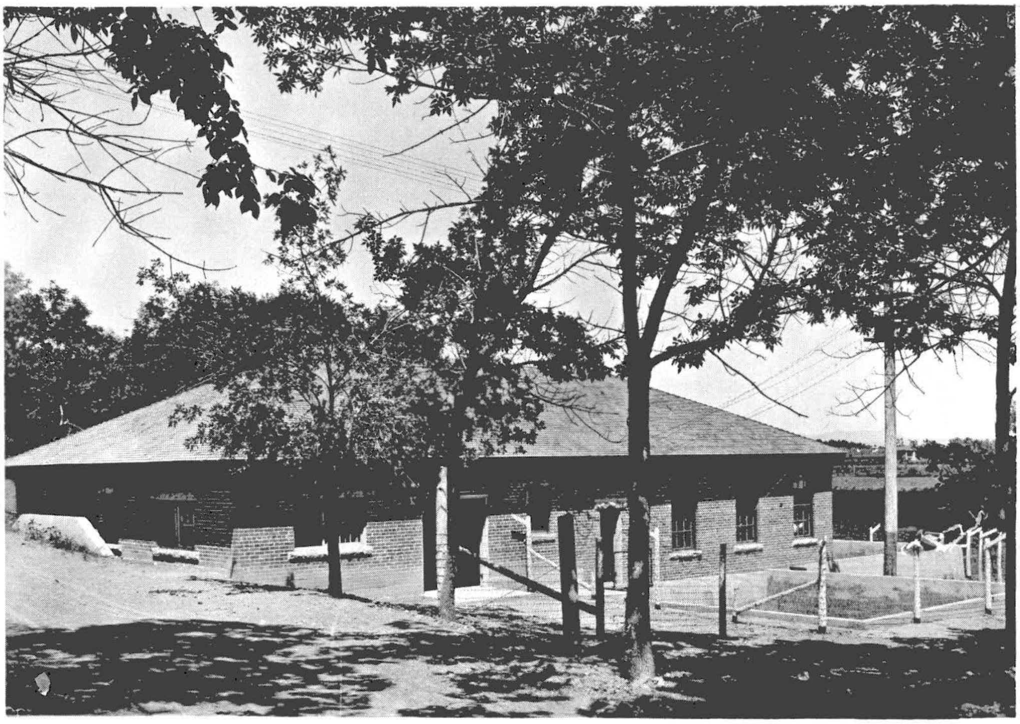


Fig. 5 Hydraulics Laboratory in 1913. (Channel from outdoor reservoir enters the building at the left side of photograph.)

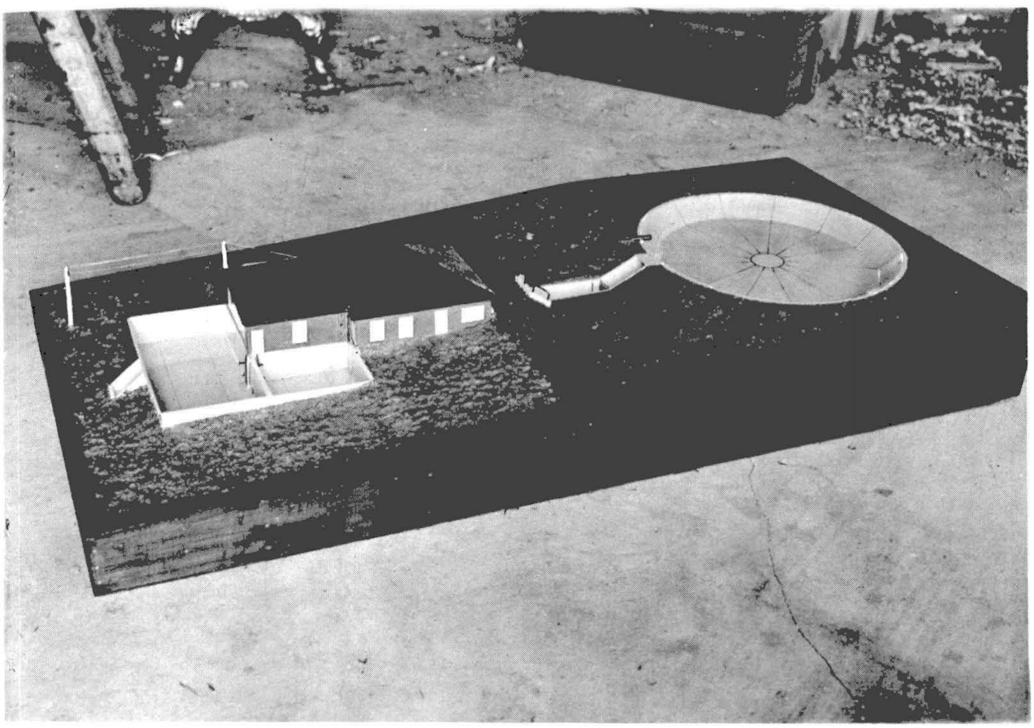


Fig. 6 Model of Hydraulics Laboratory -- First Phase of Development (showing outdoor reservoir in relation to the laboratory building and calibration tanks).

A completely water-tight, sheet copper, lining was placed inside the reservoir in 1926 so the reservoir could be used as a large scale evaporation "pan". At one time a rotating arm was fitted in this reservoir which was also used for calibration of current meters.

In 1914 a current meter calibration channel, $3\frac{1}{2}$ ft x 5 ft x 210 ft long, was installed east of the Hydraulics Laboratory. In 1938 this channel was replaced by the present current meter rating facility located north of the laboratory. This channel is 5 ft wide, 5 ft deep and 250 ft long. An electric-powered carriage capable of speeds up to 10 fps is used to tow the current meters and other flow measuring devices in calm water.

In 1938, in cooperation with the Bureau of Reclamation and the U. S. Department of Agriculture, the Hydraulics Laboratory building was enlarged to approximately 95 ft by 110 ft. The pumping system was enlarged so that the laboratory became more independent of the outdoor reservoir as a source of water supply. Following World War II the basic facilities were expanded to provide two glass-walled channels, a long variable-slope flume, a turbulence tank and fall velocity columns for sedimentation studies, and facilities for studying performance of well screens and flow of ground water.

In 1950 the laboratory building was further expanded by a 95-ft by 78-ft addition to the east. During the next year an office addition was constructed on the west end. In 1952, in cooperation with the Bureau of Aeronautics and the Bureau of Ships of the Navy Department, a wave generator, wave guides, wave absorbers, portable towing apparatus, and related equipment were installed in the 85-ft diameter reservoir. This transformed the outdoor water-supply reservoir into a unique wave basin in which model hulls could be towed in a direction oblique to the waves and the first model studies in the United States using this technique were instituted. The next photograph, Fig. 7, shows the outdoor reservoir and the Hydraulics Laboratory with the 1952 addition to the right and the 1953 office addition to the left.

The Office of Naval Research sponsored the construction in 1949 of a wind tunnel designed primarily for the purpose of studying turbulent boundary layer phenomena. This tunnel occupies part of the building shown in Fig. 8. The left half of this building is allocated to Civil Engineering Research and is 160 ft long, 60 ft wide, and 40 ft high. This space also houses the environment controlled room and will house the new wind tunnel and increased office space as required.

In 1956 construction was started on a new Engineering Center. This will house all of the engineering instruction activities of the College. Fig. 9 shows the construction activities for the new Engineering Building and its relation to the existing Hydraulics Laboratory. Fully equipped, this facility will cost approximately $2,500,000 and will provide over 60,000 sq ft of floor space to be devoted to classrooms, instructional laboratories, and offices.

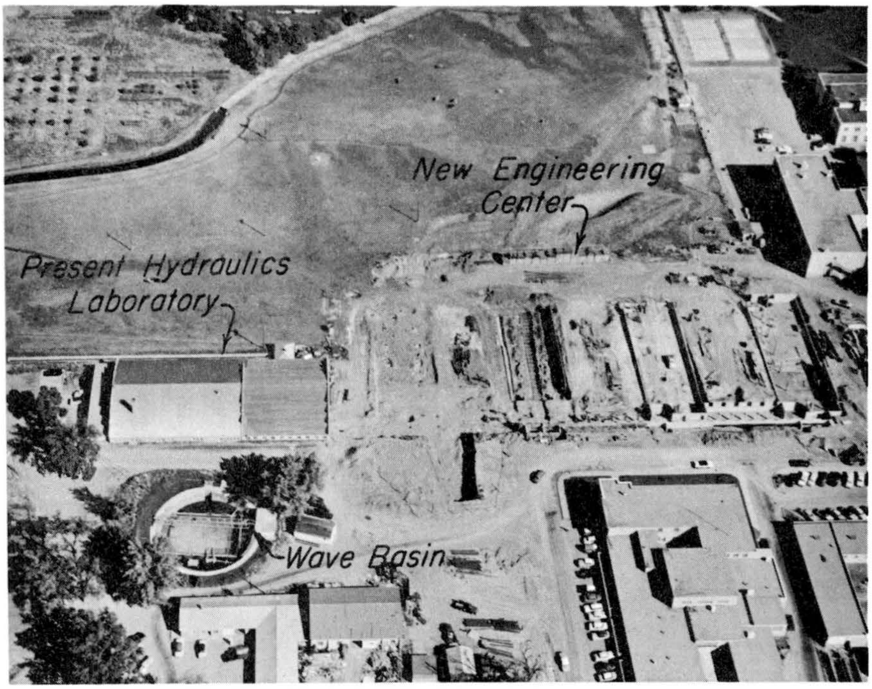


FIG. 7 EXISTING BUILDINGS—HYDRAULICS LABORATORY AND WAVE BASIN

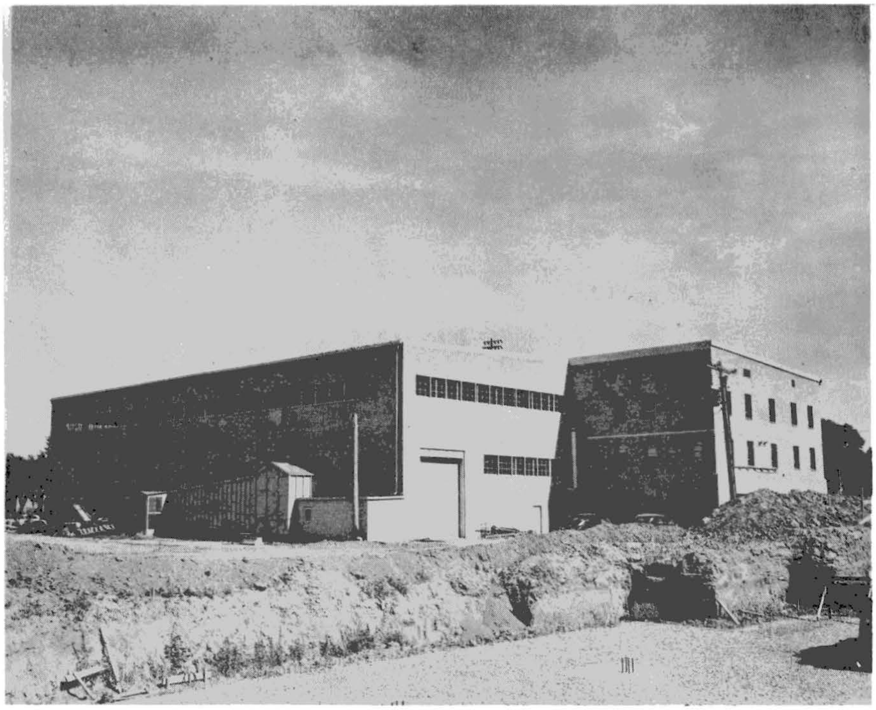


Fig. 8 Existing buildings -- Wind Tunnel in view.

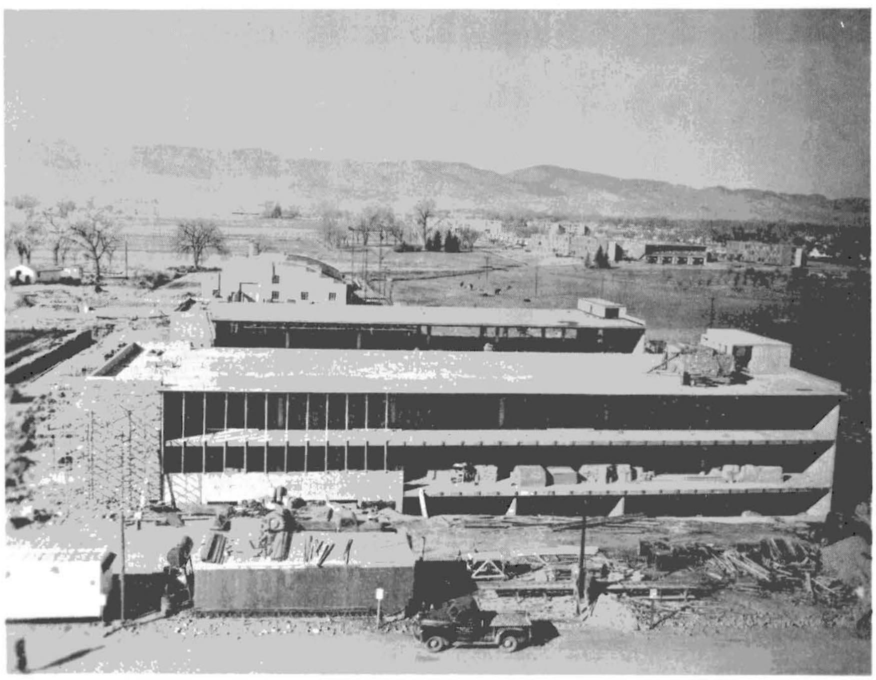


Fig. 9 New construction -- Engineering Center in foreground, Hydraulics Laboratory also shown.

B. Presently Existing Equipment

Discussion of the presently existing equipment can conveniently be divided into: (1) General Hydraulics Laboratory on the campus, (2) Hydraulics Laboratory at Bellvue, Colorado, (3) Wind Tunnel Facility, (4) Wave Basin, and (5) Environment Controlled Room.

1. Hydraulics Laboratory on the Campus

The present Hydraulics Laboratory is 200 ft long by 100 ft wide. A row of offices 18 ft wide is included along the west end.

Pumps:- Presently installed in the Hydraulics Laboratory are a 4 in. pump of 3-HP capacity, an 8-in. pump of 60-HP capacity, an 8-in. pump of 15-HP capacity, a 12-in. pump of 35-HP capacity, and a 14-in. pump of 30-HP capacity. An additional 15-in. pump of 50-HP capacity and a 20-in. pump of 60-HP capacity are now being installed. These various pumps are either stationary, supplying water to various parts of the laboratory by pipe line; or portable, so that they can be installed in any particular location needed.

Sumps:- In order to maintain adequate water supply for recirculating water through the Hydraulics Laboratory, the floor of the laboratory is underlain with sumps of various sizes. Three tanks, each 26 ft sq by 9 ft deep, are also provided. One of these tanks is calibrated volumetrically, as is a smaller tank 10 ft by 10 ft by 12 ft. They are used for the accurate calibration of various types of measuring devices. Recent additions to the sump system consist of sump-channels, 5 ft sq in cross section, which serve both as storage sumps and as channels to return the water to the pumps for further circulation.

Student laboratory:- Part of the Hydraulics Laboratory has been developed so that simple basic experiments can be conducted in connection with the academic courses in fluid mechanics. Students also use other equipment in common with research as part of their instructional laboratory program.

Experimental equipment:- Experimental equipment consists of a 2-ft glass-wall flume 3 ft high and 18 ft long, a 4-ft glass-wall flume 20 ft long, an 8-ft wide variable-slope flume 160 ft long which can be separated into two flumes 80 ft long for experiments where shorter lengths can be used, an 8-in. wide variable-slope flume with plastic walls, various Parshall flumes, measuring equipment such as weir boxes and scales, manometers, and Pitot tubes. In addition, there is a scour basin, a 250-ft long towing basin for calibration purposes, two fall velocity tubes, a 2-ft x 1-ft x 3-ft turbulence tank and a visual analysis sediment-size distribution apparatus.

2. Hydraulics Laboratory at Bellvue

An outdoor hydraulics laboratory is operated jointly by Colorado A and M College and the Agricultural Research Service. This is located on the Cache la Poudre River at the town of Bellvue near Fort Collins. It consists of a flume 14 ft wide by 70 ft long through which as much as 100 cfs can be passed and measured over a weir at the downstream end.

3. Small Wind Tunnel

The major item of equipment in the wind tunnel facility is a recirculating wind tunnel. Fig. 10 shows a plan of this wind tunnel. A second combination of transition and test section 9-ft x 9-ft sq has

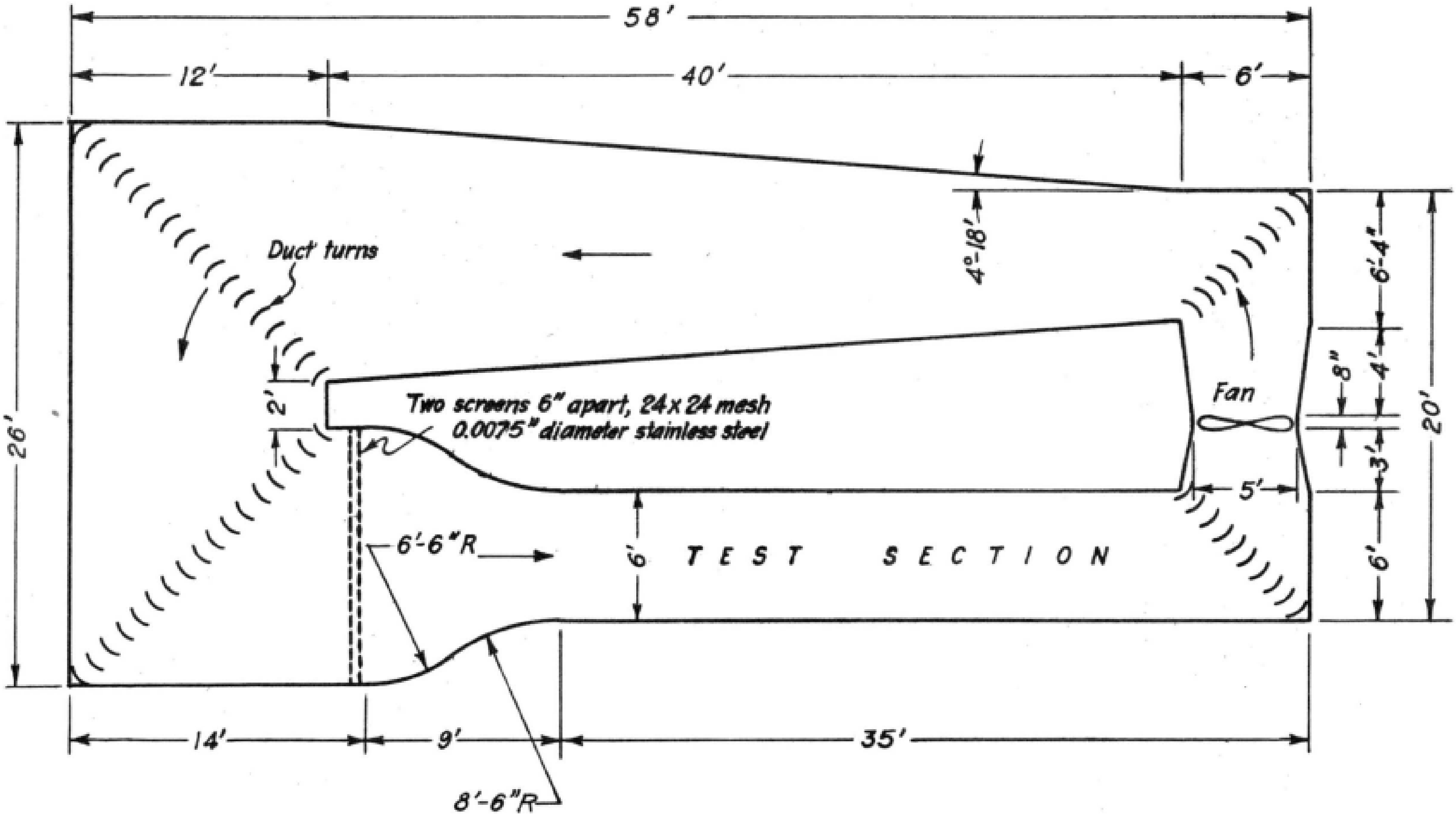


FIG. 10 PLAN OF SMALL WIND TUNNEL

been constructed and is interchangeable with the 6-ft x 6-ft sq test section shown in the figure. The test section is equipped with a traversing carriage which permits location of measuring probes at any desired point.

Several measuring instruments have been constructed or purchased. These are as follows:

<u>Instruments</u>

1. Wahlen gauges
2. Simple bridge type hot-wire anemometer
3. Constant temperature hot-wire anemometer
4. Resistance thermometer (hot-wire type)
5. Brown recorder
6. Weston integrator
7. Precision tube and Northup potentiometer
8. Various electrical meters
9. Prandtl and Pitot tubes
10. Psychrometers and thermometers

Also provided is a rotating arm system for calibrating hot-wire probes. An electrical regulating, metering and heating system is incorporated in the existing wind tunnel for heating and maintaining a constant temperature on a 6-ft x 10-ft area with a maximum output of 30 KVA.

4. <u>Wave Basin</u>

The 85-ft diameter wave basin is equipped with an instrument shed, and shallow-sea and deep-sea wave generators. The former is of the flapper type; the latter, the plunger type. A movable steel truss bridge which supports two carefully aligned rails spans the testing area.

The models are towed by a carriage which travels on these rails. The towing bridge may be oriented so that the models may be towed at any desired heading relative to the direction of wave travel.

Essential data are measured and recorded on multi-channel oscillographs. Electrical transducers used to provide the outputs are precision potentiometers, strain gauge dynamometers, micropressure gauges, accelerometers, and wave probes.

5. Environment Controlled Room

An environment controlled room is available. It is currently used for a study of the interrelation between water table depth and rate of evaporation from soil surfaces. This room has a volume of 1729 cu ft. Infrared lamps to provide up to 9 kilowatts of radiant energy are installed above the table at a distance that can be varied from 0 to 8 ft. A circular turntable 6 ft in diameter rotates under the lamps. Humidity and temperature controls are installed. A temperature of 70°F may be maintained with all lamps in operation; and lower temperatures, for lesser numbers of lamps. Control equipment is provided to maintain temperature within a range of ±3°F and relative humidity within 2 per-cent. With the sensing element now in use, the humidity can be varied over the range from 20 to 50 per cent, but elements having other ranges can easily be installed.

C. Shop Facilities

A modern shop facility is maintained by the Civil Engineering Department in connection with the fluid mechanics research program.

Excellent equipment for handling construction in metal, wood, concrete and plastic is available. All types of instruments, including electronic instruments, have been built. The primary purpose of these shops is to serve the fluid mechanics research program, but several other departments of the College are also assisted.

These shops occupy about 2,500 sq ft of floor space. The shop staff consists of a shop supervisor, five full-time men and from three to ten part-time men, the latter varying with work load. Among this staff are competent machinists, welders, carpenters and an electronics specialist.

Graduate students associated with the research program are encouraged to use these shops in constructing as much of their own equipment as is possible.

D. Library Facilities on Fluid Mechanics

For many years fluid mechanics, irrigation and hydraulic engineering have been given special attention by the Colorado A and M College Library. In these engineering fields the library is much better than average. Most of the current publications in the hydrology field as well as in the basic physical sciences are found in the library. A good collection of other supporting works is also available. New library facilities are being planned for construction under the current building program. This development will relieve many of the problems now faced by the library in meeting expanding needs.

E. Planned Future Development

Presentation of development plans will include (1) Proposed Expansions to the Hydraulics Laboratory, (2) Proposed Completion of the Wave Basin Facility, and (3) Proposed Completion of the Wind Tunnel Facility. Preliminary plans and elevations of the developments are shown. These are purely tentative and subject to detailed review by the campus planning agency and the college architect.

1. Expansion to the General Hydraulics Laboratory

The floor space for research in fluid mechanics is to be expanded approximately three times. This expansion consists of a 250 per cent increase in laboratory space and a 500 per cent increase in office floor space. This is considered to be the minimum that would be consistant with the rate of growth of the regional population and the needs for research in the hydraulics field. Figs. 11 and 12 show the existing laboratory and office facilities and the proposed expansions. Since the wave basin facility is integral with the Hydraulics Laboratory this also is shown on these figures.

The type of building tentatively proposed is probably the least expensive that could be employed and still be architectually satisfactory. The roof is formed from intersecting thin-shell barrel sections of reinforced concrete. The cantilevered overhangs have an important structural function, but also pleasant eye-appeal. The design is such that individual sections of the structure can be built as funds become available. Each section will become an integral part of the complete structure.

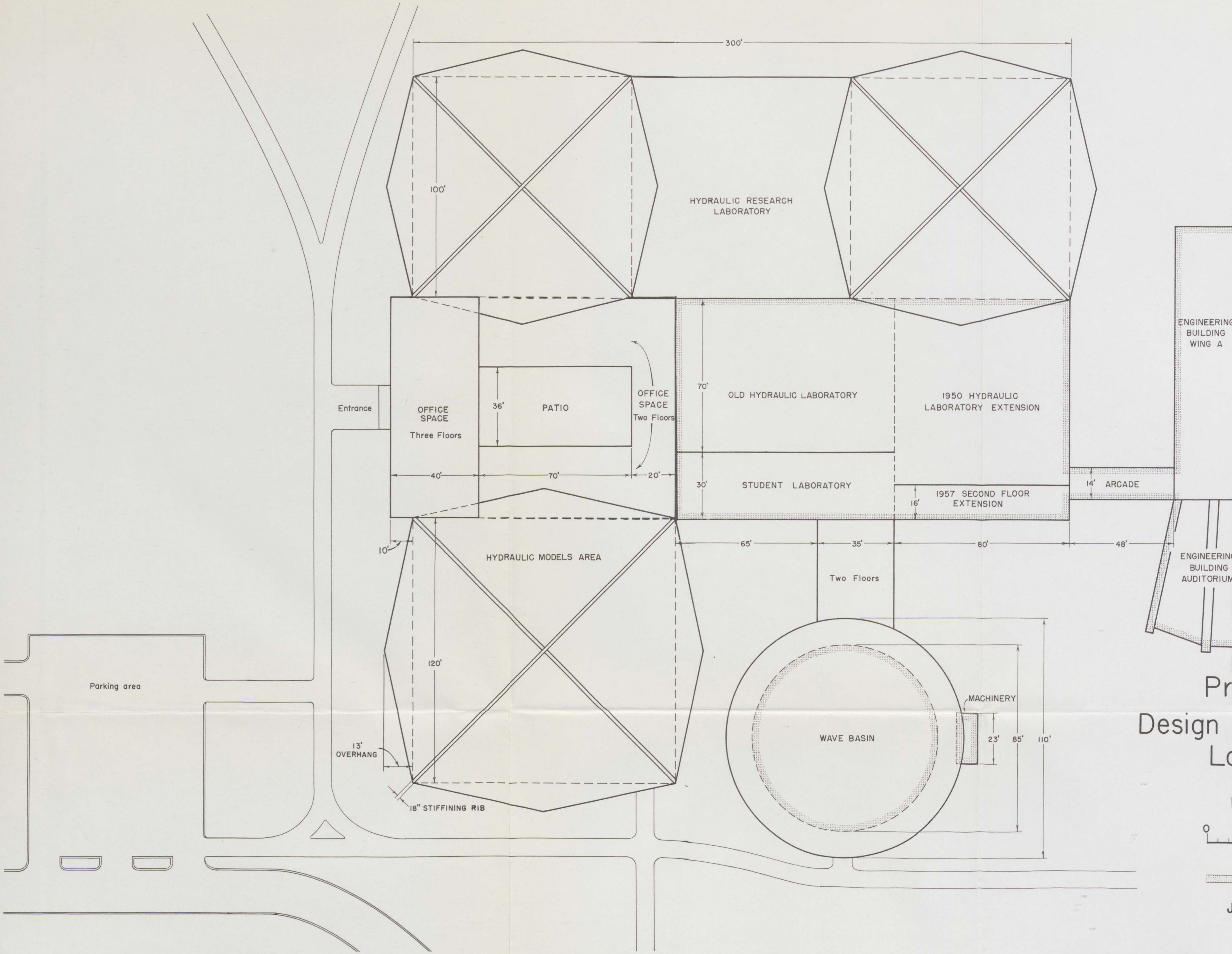
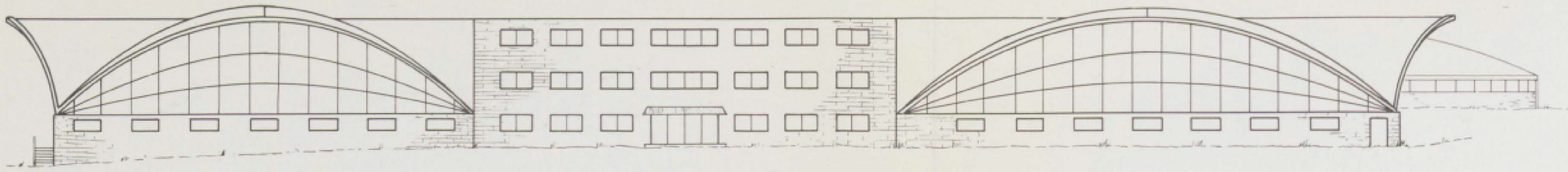


Fig. 11

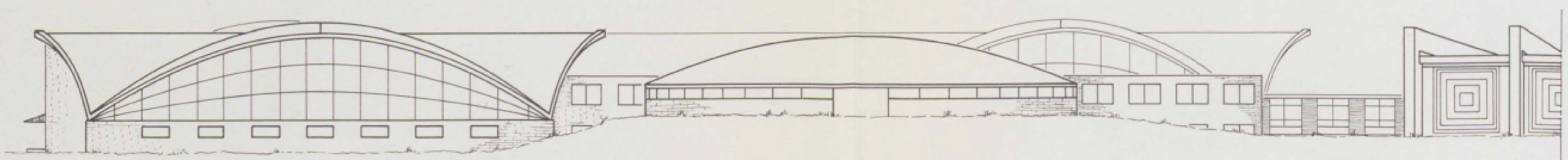
Preliminary Design of Hydraulics Laboratory

ROOF PLAN

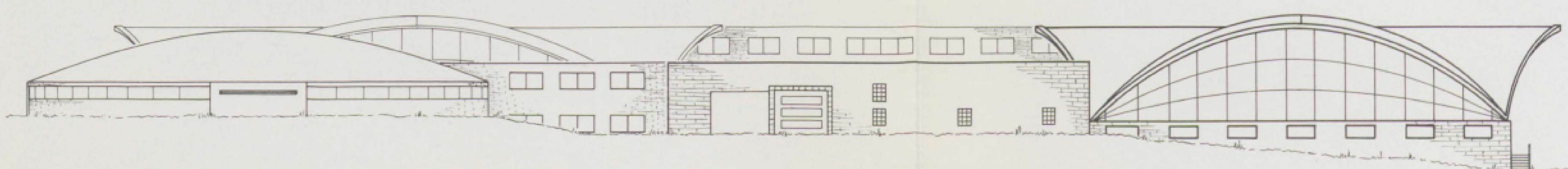
January, 1957



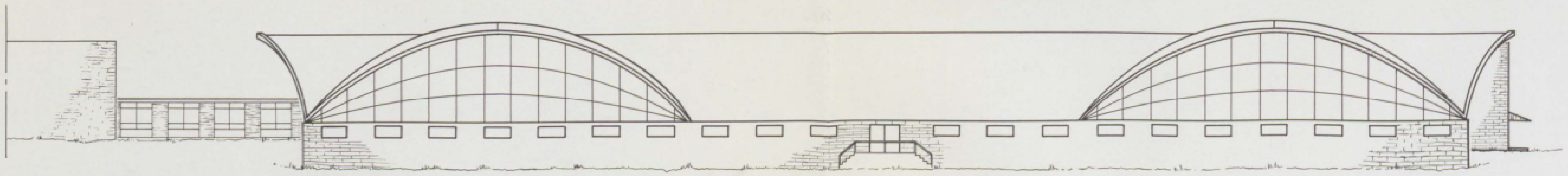
West elevation
Main entrance



South elevation



East elevation



North elevation

Fig. 12

Preliminary Design of Hydraulics Laboratory

ELEVATIONS

0 60'
Scale

January, 1957

The cost of the proposed Hydraulics Laboratory building expansion is several times the cost of the equipment needs. This is typical of hydraulic research, which requires a large expanse of floor space, but relatively inexpensive equipment.

2. Completion of the Wave Basin Facility

The wave basin facility is outdoors so that it operates only during the summer months. Even during these months successful execution of research is seriously hampered by day-time breezes, making night-time work a necessity. Completion of the facility, consisting principally of construction of a dome to cover the wave basin, would make possible approximately four times as much research volume, under vastly improved working conditions.

Fig. 13 shows the proposed steel lamella dome and appurtenant office and work areas required. Considerable study has been made of various designs, such as thin-shelled reinforced concrete, fiberglass domes, and inflated plastic bags. The steel lamella design, supported on columns and covered with a thin concrete shell gives by far the most economical structure. This design is architectually pleasing and has been used on university campuses. The two-floor section connecting the wave basin to the Hydraulics Laboratory is of simple reinforced concrete and brick design.

3. Completion of the Wind Tunnel Facility

Colorado A and M College has been slowly increasing its low-velocity wind tunnel research facilities for several years. At the

PERTINENT FEATURES

- WAVE BASIN COVERED BY LAMELLA-FRAMED DOME – SEE SMALL CUTAWAY SHOWING CHARACTERISTIC DIAMOND PATTERN FORMED BY INTERSECTING RIBS.
- LAMELLA DOME MAY BE THIN CONCRETE SHELL SUPPORTED BY STRUCTURAL STEEL RIBS.
- LOAD OF DOME TRANSFERRED TO SHALE FORMATION BY TWELVE REINFORCED CONCRETE COLUMNS.
- MASONERY VENEER TO BE APPLIED TO PRESENT MACHINERY SHELTER.

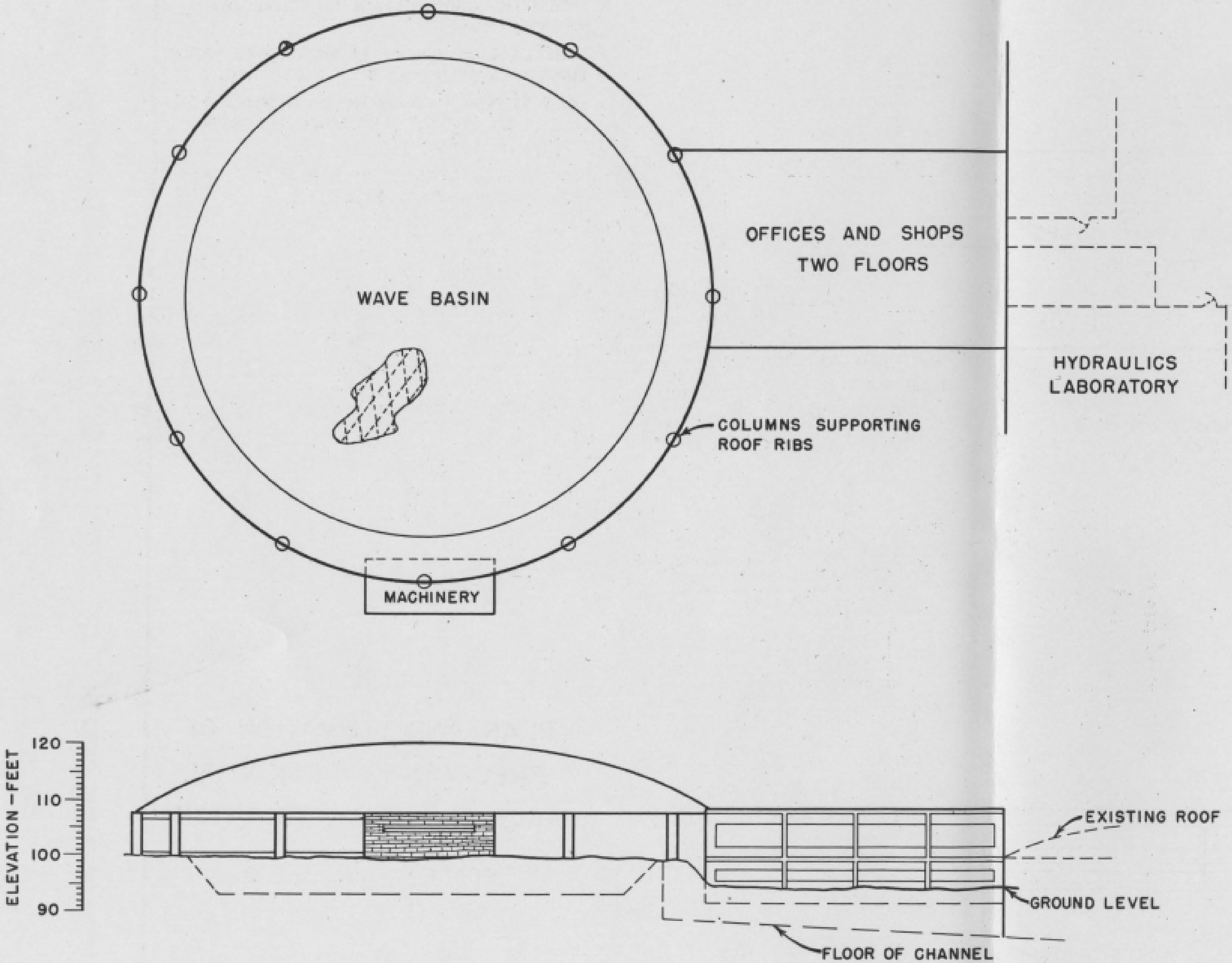


FIG. 13

PLAN AND ELEVATION OF PRELIMINARY DESIGN OF WAVE BASIN CONSTRUCTION

SCALE 0 — 20'

present time a new wind tunnel is under construction. However, resources for this development are presently extremely limited and considerable financial assistance is needed if this facility is to become highly productive in the near future.

Fig. 14 is an isometric view showing the building housing the wind tunnels. Fig. 15 is a plan view showing both the existing wind tunnel and the one now under construction. The first step will be to complete the working test section of the new wind tunnel so that experimental work can begin. Then, while the first results are being obtained, expansion of the facility will proceed. This will include construction of the return duct on top of the building and installation of temperature control and air conditioning.

Fig. 16 is an elevation of the new wind tunnel now under construction. Only the lower left hand intake section has been constructed to date -- under the sponsorship of Air Force Cambridge Research Center, whose funds are quite limited in this case.

F. Equipment Needs

The equipment needed to conduct an adequate research program as proposed earlier is listed below. Many instrument items are not included since much of this type of equipment can be obtained on loan through Defense Department contracts or will be owned by the College. The equipment needs are split into three categories: Hydraulics, Wave Basin and Wind Tunnel.

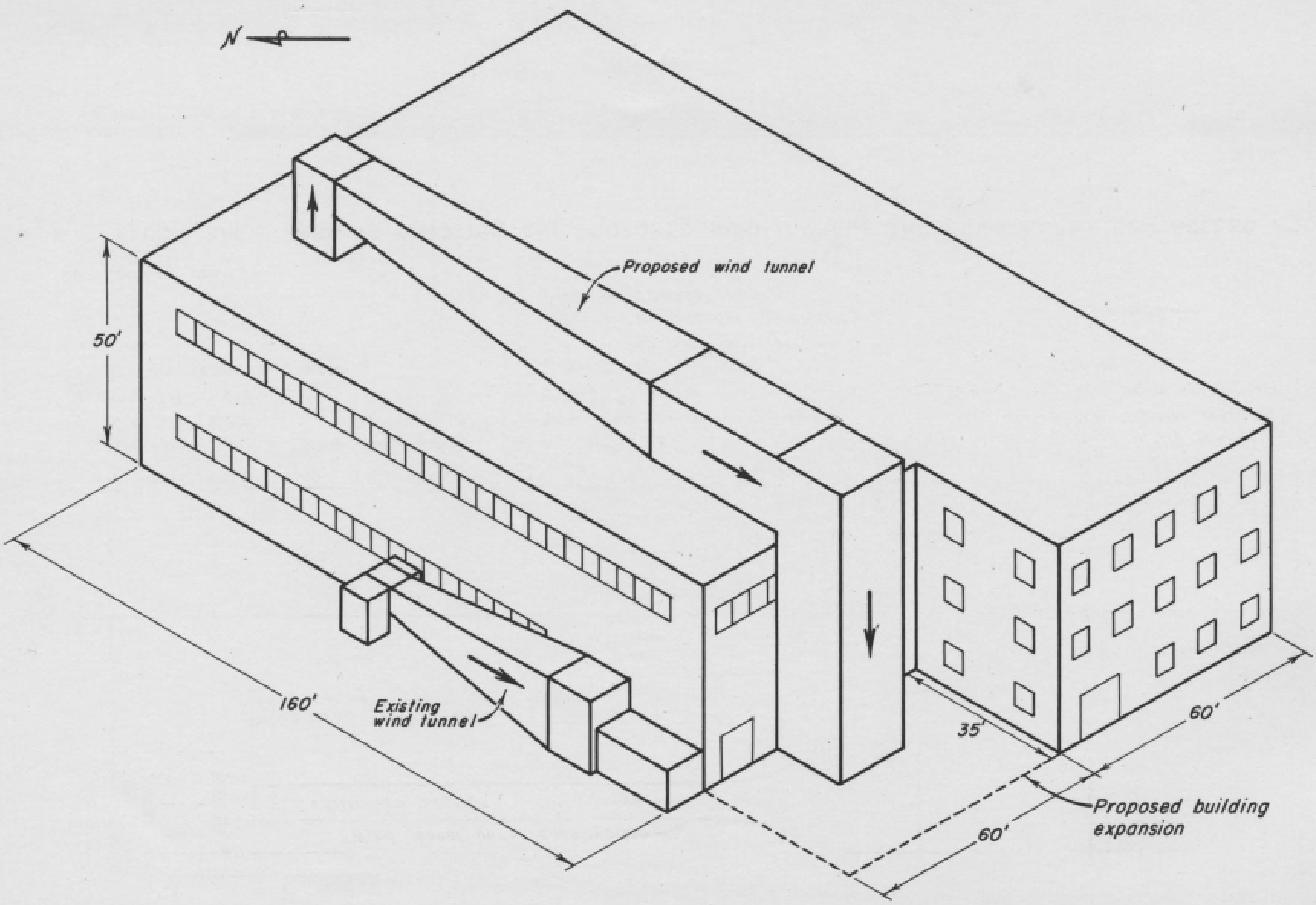


FIG. 14 ISOMERTIC VIEW SHOWING WIND TUNNELS AND EXISTING AND PROPOSED APPURTENANT BUILDING

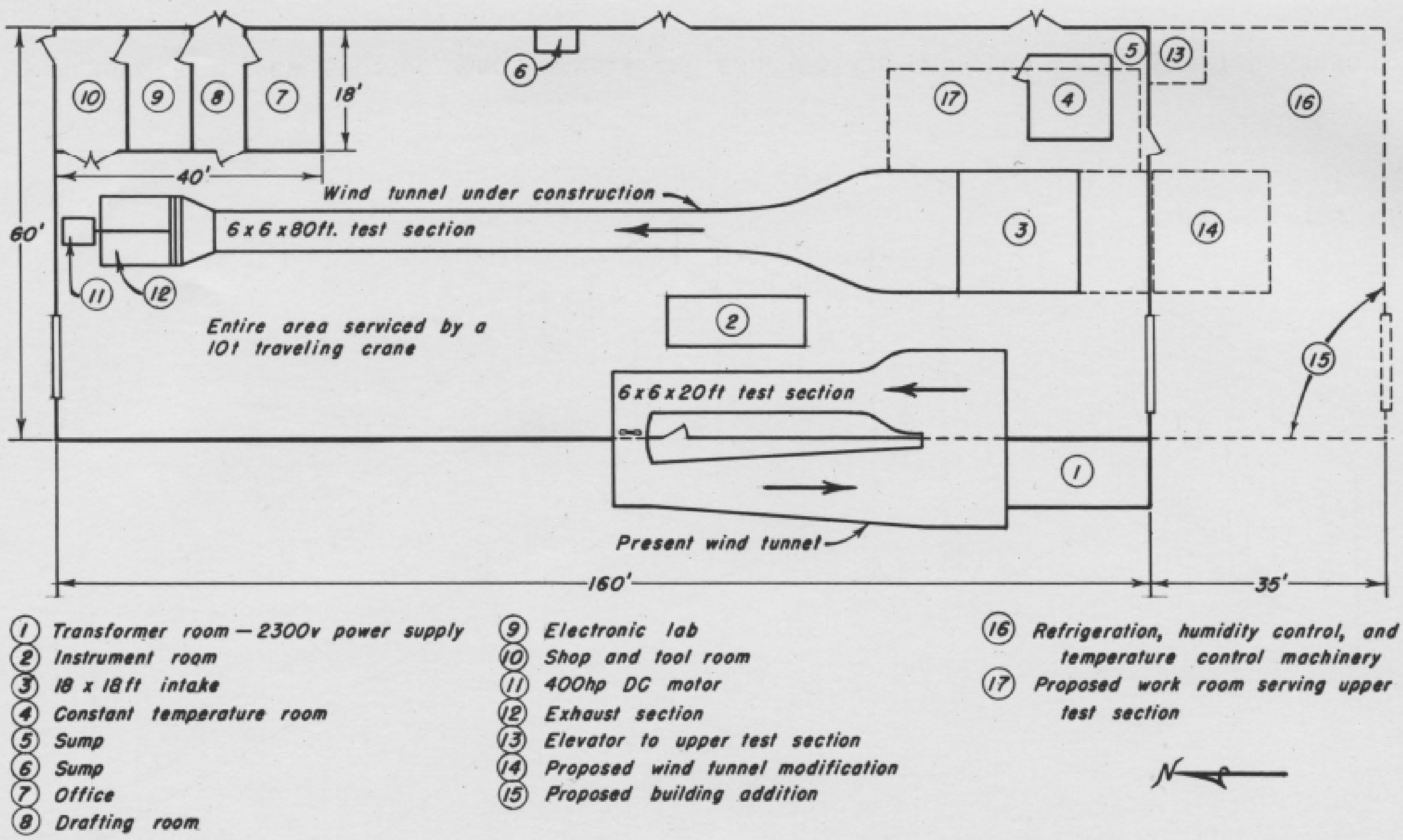


FIG. 15 FLOOR AREA SHOWING EXISTING AND PROPOSED WIND TUNNELS AND ENVIRONMENT CONTROLLED ROOM

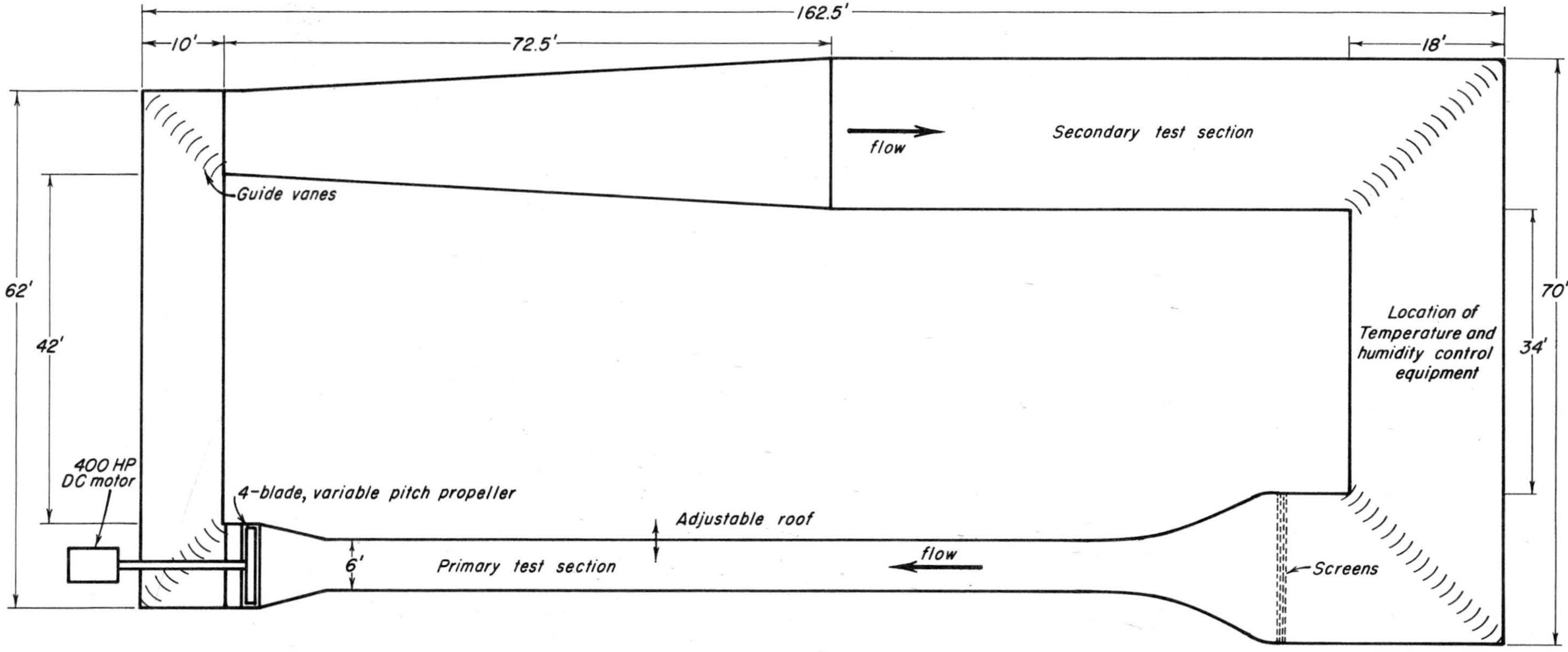


FIG. 16 ELEVATION OF NEW TUNNEL NOW UNDER CONSTRUCTION

Equipment for general services, and for construction and maintenance shops is not included herein. Such equipment will be available through the regular activities of the College.

The experimental hydraulics research equipment needs are as follows:

1. A $2\frac{1}{2}$-ft wide variable slope flume.
2. A 4-ft wide variable slope flume.
3. A 16-ft wide variable slope flume.
4. A water tunnel.
5. Six pumps with appurtenant pipes, valves, starters and wiring.
6. A wind erosion test tunnel.
7. A sediment analysis laboratory.
8. Two glass-walled flumes.
9. Two scour basins.
10. Mechanical instruments such as stage recorders, point gauges, manometers, Venturi meters and orifice meters and Pitot tubes.
11. Electronic instruments, including somoscope, pressure frequency recorder, wave filter, oscilloscope, counters, turbulence probe, and electronic strobe lights.
12. Office equipment for 40 researchers and supporting staff.

The Wave Basin requires the following equipment:

1. A wave maker capable of generating a complex stochastic seaway.

2. Model powering equipment. Currently models are towed, an unrealistic condition.

3. An analog computer (also to be used by wind tunnel and hydraulics).

4. Electronic equipment such as data encoders, transducers, and wave generator controls.

5. Office equipment for 10 researchers and supporting staff.

For the Wind Tunnel facility, the following are equipment needs:

1. Completion of new recirculating wind tunnel.

2. Change power system of existing wind tunnel from a diesel engine to a DC electric motor.

3. Heating equipment and controls.

4. Refrigeration equipment and controls.

5. Humidity equipment and controls.

6. Hot-wire anemometer and thermometer equipment.

7. Gas sampling equipment.

8. Photographic equipment (also used by wave basin and hydraulics).

9. Balances and pressure tranducers.

10. Schlieren apparatus.

11. Office equipment for 15 researchers and supporting staff.

V

FINANCIAL STATUS AND FUTURE REQUIREMENTS

During the next few years, Colorado A and M College, as will all American universities, experience a great expansion in enrollment and in educational activities. The thesis behind the various facets of this proposal is that research facilities must keep pace with the over-all development of a regional university, especially in the particular lines of research in which the university specializes. This means that fluid mechanics research facilities at Colorado A and M College must greatly increase in the next seven years. To do this and still do the required educational job is beyond the financial resources of the state.

The information contained in the following tabulations is designed to present the financial needs for a minimum program in fluid mechanics research. These needs are developed on the presumption that in the future, as in the past, Colorado A and M College should maintain its position as one of the several institutions in the United States specializing in this field. As background for these needs, an estimate of the present value of existing facilities is presented under Item A which shows this total to be $541,000. Estimated cost of needed new buildings, including utilities, landscaping and access roads is detailed under Item B and totals $965,000. Item C lists the estimated cost to replace certain worn out equipment and purchase necessary new equipment. This totals $1,105,000. In Item D, an estimate is made of annual operating costs, i.e., utilities, maintenance of motors, etc. Under Item E, an annual budget for fundamental, non-contract sponsored, research totaling $100,000 is proposed. Items F and G present a summary of the financial needs and set forth proposed annual support by the National Science Foundation over the next ten years.

A. Present Value of Facilities and Equipment.

1.	Land	$ 9,000
2.	Equipment	177,000
3.	Buildings and utilities	355,000
		$541,000

B. Estimated Cost of Research Facility Development.

1.	North wing, Hydraulics Laboratory building	$300,000
2.	South wing, Hydraulics Laboratory building	160,000
3.	West office unit, Hydraulics Laboratory building	140,000
4.	Dome over wave basin	67,000
5.	Wind tunnel building additions	100,000
6.	Building connecting wave basin to Hydraulics Laboratory	45,000
7.	Utilities (gas, light, water, heat)	113,000
8.	Landscaping, lands, parking lot, etc.	15,000
9.	Access roads to Hydraulics Laboratory	25,000
		$965,000

C. Estimated Cost of Equipment Needs.

1.	Office equipment	$ 80,000
2.	Wave maker	100,000
3.	Wave basin model powering equipment	15,000
4.	Analog computer	20,000
5.	Water tunnel	20,000
6.	Open channel flumes	62,000
7.	Hydraulics Laboratory pumps, motors, starters, pipe and valves	40,000
8.	Wind erosion tunnel	10,000
9.	Sediment analysis laboratory	8,000
10.	Glass-walled flumes	16,000
11.	Hydraulics Laboratory, mechanical instruments	5,000
12.	Scour basins	7,000
13.	Hydraulics Laboratory, electronic instruments	15,000
14.	Wind tunnel -- power equipment	100,000
15.	Wind tunnel -- test sections	60,000
16.	Wind tunnel -- recirculation ducts	125,000
17.	Wind tunnel -- insulation of shell	25,000
18.	New power unit for existing wind tunnel	12,000
19.	Wind tunnel -- temperature, humidity control equipment	130,000

20.	Hot wire anemometers with special analysis circuits	$ 105,000
21.	Gas sampling equipment	5,000
22.	Photographic equipment	25,000
23.	Balances and pressure transducers	80,000
24.	Schlieren equipment	40,000
		$1,105,000

D. Estimated Annual Operating Costs.

1.	Maintenance of motors and equipment	$ 6,000
2.	Heating	4,000
3.	Light and power	5,000
4.	Gas	1,000
5.	Water	500
6.	Materials	3,500
7.	Secretarial, janitorial, accounting	5,000
8.	Communications	1,500
9.	Travel and conferences	3,000
10.	Assistance to publish papers	1,500
	Annual operating costs	$ 31,000
11.	Annual contribution from College and Foundation research	$ 12,000
12.	Annual operating cost requested of National Science Foundation (**probable maximum**)	$ 19,000

E. Proposed Annual Support for Fundamental Research.

1.	Boundary layer fluid mechanics	$ 20,000
2.	Instrumentation research	20,000
3.	Fundamental fluvial hydraulics	25,000
4.	Rigid boundary hydraulics	15,000
5.	Water wave phenomena	20,000
		$ 100,000

F. Schedule of Utilization of Capital Investment Funds.

Fiscal Year	Requested of NSF	Other Sources (State and Industrial)
1958	$ 105,000	$ 40,000
1959	205,000	40,000
1960	205,000	50,000
1961	205,000	50,000
1962	205,000	50,000
1963	205,000	100,000
1964	205,000	100,000
1965	205,000	100,000
	$1,540,000	$530,000

G. Total Funds Requested Annually of National Science Foundation Through 1967.

Below is shown the total funds requested of NSF through Fiscal Year 1967. This includes the budget for buildings, equipment, maintenance, and non-contract sponsored research. During the first years the budget includes only part of Items D and E.

Fiscal Year	Operating Costs	Research Support	Capital Investment	Total
1958	9,000	36,000	105,000	150,000
1959	15,000	60,000	205,000	280,000
1960	15,000	80,000	205,000	300,000
1961	15,000	90,000	205,000	310,000
1962	15,000	90,000	205,000	310,000
1963	15,000	90,000	205,000	310,000
1964	10,000	95,000	205,000	310,000
1965	10,000	95,000	205,000	310,000
1966	10,000	100,000	---	110,000
1967	10,000	100,000	---	110,000
	$124,000	$836,000	$1,540,000	$2,500,000

H. Summary

The funds requested of NSF for the next ten fiscal years, through fiscal 1967, for research and facilities totals $2,500,000. Of this total $1,540,000 is for buildings and equipment and $965,000 is for research and operation. The total investment in buildings and facilities through fiscal 1965 by the College and industry, exclusive of special facilities sponsored by contract research, is estimated at $1,051,000, including present value of facilities.

VI

SUMMARY

Colorado A and M College has conducted research in hydraulics and fluid mechanics, and related areas; especially as applied to irrigation and water conservation since 1885. Through the years a laboratory facility, consisting of a general hydraulics laboratory, an outdoor hydraulics laboratory, a climatological wind tunnel, an environment controlled room, and an outdoor wave tank have been developed. This facility is served by fine library facilities, a modern shop and by appropriate appurtenant equipment. The present value of these facilities is estimated at $541,000. There has also been organized a competent research staff serving the general field of fluid mechanics. This staff presently enjoys considerable reputation in their specialty.

With increasing population and increased use of the water resource, the present facilities are already grossly inadequate to conduct the needed program of basic and applied research. Present trends indicate that the inadequacy of the research facilities is a condition which will not be rectified soon; rather, it appears that the pressure of population necessitating more research will increase at an increasing rate. In the western states and perhaps in the entire nation, water is the limiting natural resource. Every effort must be made to use it more economically if basic minimum needs are to be met. Facing a greatly increased teaching responsibility, it is doubtful if Colorado, in common with other states of the region, will be able to provide funds for the minimum research facility; accordingly, financial support from the National Science Foundation is requested.

Over and above the factors of long research experience in hydraulics, an already organized staff, and some existing laboratories; there are several advantages inherent in locating laboratories of the nature requested on the Colorado A and M campus. The location is near the center of North America's sub-humid region -- the region where water problems will become most critical first. There are also some national security aspects of hydraulics research which point up the wisdom of locating such a facility away from the seacoasts in a region having low military target priority.

Research efforts in the hydraulics and fluid mechanics field at Colorado A and M College have been slanted toward conservation and better management of water. Important measuring devices and principles leading to the design of hydraulic structures have been developed. An attack has been made on problems associated with open channel flow, especially in alluvial channels. Considerable effort has been devoted to ground water and well engineering research. Drainage and the prevention of seepage have received attention. The evapo-transpiration due to crops and methods for forecasting run-off and surface water supplies have been investigated. In the wind tunnel, model studies of the atmospheric boundary layer have been initiated and progress has been made toward a better understanding of the transfer processes involved in the lower atmosphere. This work has required the development of considerable basic instrumentation. It is important fundamentally because of its bearing on moisture conservation in the Great Plains, wind erosion, and control of atmospheric contamination. A unique wave basin has been developed and model tests for seaworthiness of ship and seaplane hulls, towed obliquely to a wave front, have been pioneered.

Future research will be generally in the same categories as the present effort. Presently, the effort toward fundamental understanding is relatively inadequate, so that emphasis on more generalized, fundamental studies is envisioned. This is especially true in the fields embracing open channel flow, erosion and sedimentation, hydraulic structures, atmospheric boundary layer phenomena, seaworthiness, moisture conservation, rainfall and climate, and ground water. Studies leading to actual engineering application should be accelerated in all of these fields in order to meet present and future demands on the water resource.

A ten-year program covering the development of the needed research facilities is presented. Briefly, the space available for general hydraulics research is to be increased about two and one-half times. The wave basin, presently out-of-doors, will be covered and the non-recirculating climatological wind tunnel now under construction will be converted to a circulating type and fully climate conditioned. Appropriate service equipment and office space will also be provided. Capital investment necessary for such a facility is estimated at $2,070,000 of which it is proposed that the National Science Foundation provide $1,540,000. The remainder would be provided by the College and from industrial sources. It is also proposed that the National Science

Foundation provide $124,000 to help defray operating costs and $836,000 to help support basic research over the next ten years. The total funds provided by the National Science Foundation over the next ten year period would be $2,500,000.

In summary, a concerted attack will be made on problems associated with the management, control and use of water, especially, as they relate to the arid and semi-arid west, but also in general hydrology. The nucleus of a staff of skilled personnel, library facilities, and general intellectual environment is already developed. A plan is presented whereby this potential may be expanded and more effectively utilized to gain a highly essential understanding of the best means of conserving water, the nations most critical natural resource.

VII

RESEARCH STAFF

The research staff of the Civil Engineering Department has had a great deal of experience in research in fluid mechanics and hydraulic engineering. This staff consists of personnel on the regular academic staff engaged part-time in teaching and also of full-time research engineers. A number of graduate assistants are employed by the staff. Visiting consultants are employed from other universities and commercial organizations to help on special problems or use unique facilities. Government agencies often make arrangements to send researchers to utilize the facilities for short periods of time.

This chapter consists of two parts: (A), a list of staff members, with information on their academic degrees, background, and major fields of interest and (B), a section on the graduate program of the department.

A. List of Personnel, Degrees, Background and Major Fields

T. H. Evans, Dean of Engineering and Professor of Civil Engineering. He holds B.S. and M.S. degrees in civil engineering from the California Institute of Technology. Post-master's work was done in mechanics at the University of Michigan and Carnegie Institute of Technology. Contract law was studied at Emory University. He has had 28 years' experience in professional engineering, teaching, and administration. His professional engineering experience includes highway construction and design, and dam construction. He has taught civil engineering and mechanics in all grades from Teaching Fellow to Professor at California Institute of Technology, Yale Engineering School, University of Virginia, Georgia Institute of Technology and Colorado A and M College. Dean Evans served as Head of Civil Engineering at Georgia Institute of Technology. His principal fields of interest are engineering mechanics, contract law and educational development and administration. He has published numerous technical and semi-technical articles on photoelasticity, mechanics, surveying, artificial precipitation, professional aspects of engineering, and engineering education. He is a Registered Professional Engineer in Virginia, Colorado and Georgia.

D. F. Peterson, Jr., Professor and Head of Civil Engineering. He holds a B.S. degree in civil engineering from Utah State Agricultural College, M.C.E. and D.C.E. degrees from Rensselaer Polytechnic Institute. He has had six years' experience in professional engineering work and fifteen years' experience in research and teaching at the University of Washington, Rensselaer Polytechnic Institute, Utah State Agricultural College and Colorado A and M College. His primary interests include structural engineering, irrigation engineering, seepage, drainage, consumptive use of water, soil mechanics and river utilization. He has published numerous articles and bulletins on structural analysis, irrigation engineering and seepage. He is a Registered Professional Engineer in Colorado and Utah.

M. L. Albertson, Professor of Civil Engineering, holds a B.S. degree in civil engineering from Iowa State College and an M.S. and Ph.D. in hydraulic engineering from the State University of Iowa and the degree of Doctor of Physical Sciences from the Université de Grenoble, France. He has had fourteen years' experience in fluid mechanics research. His experience has been primarily with problems involving design and development of hydraulic structures, boundary layer studies and diffusion. He pioneered in the development of the use of a wind tunnel to study boundary layer transfer phenomena. He has written or collaborated on a number of technical papers, and together with the other authors of the paper, was awarded the ASCE Emil Hilgard Prize in 1951 for a paper on diffusion of submerged jets. In 1948 he received the J. C. Stevens Award from the American Society of Civil Engineers for a discussion of a paper on evaporation. He is a Registered Professional Engineer in Colorado.

E. W. Lane, Professor of Civil Engineering, has been working in the field of hydraulics since 1912. He holds a B.S. degree from Purdue University and the degree of Civil Engineer from Cornell University. His work has been primarily concerned with flood control, sedimentation and other problems related to river control. He was formerly head of the hydraulics laboratories of the U. S. Bureau of Reclamation, and later head of the Iowa Institute of Hydraulic Research. His most recent assignment prior to joining the staff at Colorado A and M College was special consultant to the chief engineer of the Bureau of Reclamation on problems associated with erosion and sedimentation engineering. He has written a great many papers of scientific and engineering interest, both of a fundamental and an applied nature.

R. E. Glover, Civil Engineer, holds a B.S. degree in civil engineering and the degree of Civil Engineer from the University of Nebraska. He also holds an M.S. degree in applied mathematics from the University of Colorado. His engineering experience extends over 39 years including one year of college teaching, 15 years as the head of a group organized to deal with the mathematical aspects of engineering work for the U. S. Bureau of Reclamation, 3 years of laboratory research, one year in aircraft structural analysis, and one year as a hydraulic engineer. The remainder of Mr. Glover's career has been spent in the design of dams and other irrigation structures. He has written or collaborated on many papers on heat flow, analogs, soil mechanics, dam design, ground water hydraulics and salinity propagation in estuarine channels. He is a Registered Professional Engineer in Colorado.

Arthur T. Corey, Civil Engineer, holds a B.S. degree in agriculture from the University of Maryland. He studied civil engineering at Pennsylvania State University in the Army Specialized Training Program during World War II. He also holds the degrees of M.S. in irrigation engineering from Colorado A and M College and Ph.D. in soil physics from Rutgers University. His experience in research includes a year with the Division of Irrigation of the University of California, and four years with the Gulf Research and Development Company. His primary interests include fluid flow in soil and porous rock, and evaporation. He is the author of several papers on fluid flow and co-author of a paper dealing with the removal of water from soil by plants.

Carl Rohwer, Collaborator, Senior Irrigation Engineer (retired), Agricultural Research Service, U. S. Department of Agriculture. He holds a B.S. degree in civil engineering from the University of Nebraska and the degree of Civil Engineer from Cornell University. He has had forty years' engineering experience, most of it in irrigation research, but including irrigation water supply investigation and irrigation project construction. His research studies have been concerned with water measurement, water utilization, evaporation from free water surfaces, evapo-transportation, seepage from canals, canal lining, ground-water development, removal of silt from irrigation water supplies, and forecasting of stream flow from mountain snow cover. Reports on these studies have been published in bulletins, technical papers and articles.

W. E. Code, Irrigation Engineer. He holds a B.S. degree in civil engineering from the University of Michigan. He has had 28 years' experience in irrigation engineering, principally in the subjects of irrigation practices and ground water occurrence and development in Arizona and Colorado. He is the author of numerous bulletins on irrigation, wells and pumping for irrigation. He is a Registered Professional Engineer in Colorado.

R. L. Parshall, Collaborator, Senior Irrigation Engineer, U. S. Department of Agriculture (retired). He holds the B.S. degree in civil and irrigation engineering from Colorado A and M College. He taught civil engineering and physics at Colorado A and M College, 1904 to 1913. From 1913 to 1948 he was irrigation engineer for the U. S.

Department of Agriculture. He was in charge of the Fort Collins station from 1918 to 1948. He assisted in the design and construction of the Hydraulics Laboratory, 1910-11, and constructed the Bellvue Hydraulics Laboratory in 1919. He conducted investigations of water measuring devices, sand traps and other irrigation devices and designed recording and integrating instruments useful in irrigation practice. He initiated run-off forecasting using snow surveys in Colorado and Wyoming in 1935.

Since retirement, Mr. Parshall has continued his interests in irrigation hydraulics, conducting further studies of sand traps, and designing and building electrical automatic flow regulators and water measuring devices. He has also investigated by model tests the principle of the centrifugal desilting of bed load in channels and demonstrated the possibility of electrical precipitation of colloids.

J. E. Cermak, Associate Professor of Civil Engineering. He holds B.S. and M.S. degrees in civil engineering at Colorado A and M College. Course requirements were completed for the Ph.D. degree in engineering mechanics at Cornell University, 1955. He has had nine years' experience in teaching and research at Colorado A and M College. His efforts have been primarily in the fields of mechanics and fluid dynamics especially as related to boundary layer transfer. He was associated in a responsible capacity with the development of a wind tunnel for studying atmospheric boundary layer problems. He has published several papers and reports principally in boundary layer phenomena. He is a Registered Professional Engineer in Colorado.

N. A. Evans, Associate Professor and Head of Agricultural Engineering. He holds a B.S. degree in agricultural engineering from South Dakota State College and an M.S. degree in irrigation engineering from Utah State Agricultural College. He has post-master's work in irrigation engineering at Colorado A and M College. He has had four years of teaching and research work in irrigation and drainage at North Dakota Agricultural College, one year as research assistant at Colorado A and M College on wind tunnel studies of evaporation from a lake surface, and five years of teaching and research in irrigation and drainage at Colorado A and M College. His major research interest is in irrigation practice and drainage problems. He is a Registered Professional Engineer in Colorado.

A. R. Chamberlain, Associate Civil Engineer and Research Coordinator. He holds a B.S. degree from Michigan State University and an M.S. degree from the State College of Washington in agricultural engineering, and a Ph.D. degree in irrigation engineering from Colorado A and M College. He has had five years' experience in fluid mechanics research. His principal field of interest is in theoretical and applied fluid mechanics and experimental hydraulics. He was employed by Phillips Petroleum Company as a research engineer for several months, before going to the Université de Grenoble, France on a Fulbright Grant. He has published papers on water measuring devices and on sediment transport in pipes having different boundary roughness.

H. K. Liu, Assistant Professor of Civil Engineering. He holds the degree of B.S. in civil engineering from National Northwest College of Engineering, China; the M.S. degree in hydraulic engineering from the State University of Iowa, and a Ph.D. degree in hydraulic engineering from the University of Minnesota. He presently teaches a graduate course in open channel flow. He has had five years' experience in engineering practice and eight years' experience in fluid mechanics research. His principal field of interest is in open channel flow especially as related to alluvial channel roughness. He has published discussions and papers on the mechanics of sediment transport.

J. R. Barton, Assistant Professor of Civil Engineering. He holds an M.S. degree in hydraulics from the State University of Iowa and has completed his study of courses toward a Ph.D. in irrigation engineering at Colorado A and M College. He has ten years university experience of which seven of those years have been devoted completely or partially to research and the remainder to teaching. His principal fields of interest are experimental fluid mechanics and sediment transport. He is the author of several research reports in these fields. He is a Registered Professional Engineer in Utah.

A. C. Spengos, Assistant Civil Engineer. He holds a B.S. degree in electrical engineering from Robert College and an M.S. degree in hydraulic and electrical engineering from the State University of Iowa. He has had ten years' experience in professional engineering work, including eight years in research, at the Iowa Institute of Hydraulic Research and Colorado A and M College. His principal fields of interest are boundary layer phenomena, micrometeorology and wind tunnel instrumentation. He has published several papers on wind tunnel studies in the field of micrometeorology.

I. S. Dunn, Assistant Professor of Civil Engineering. He holds B.S. and M.S. degrees in civil engineering from Utah State Agricultural College and is a Ph.D. candidate at Stanford University, 1957. He has had research experience in soil mechanics, applied mechanics, interaction of ships and waves, and erodibility of cohesive soils.

M. E. Bender, Assistant Professor of Civil Engineering. He holds a B.S. degree from Colorado A and M College and an M.S. degree from Cornell University, both in civil engineering. His principal fields of interest are structural and soils engineering, surveying and highways. He has had two years' experience in professional engineering work, and five years' experience in teaching at Colorado A and M College. He is a Registered Professional Engineer in Colorado.

H. H. Schweizer, Assistant Professor of Civil Engineering. He holds a B.S. degree in electrical engineering from the University of Colorado and an M.S. degree in irrigation engineering from Colorado A and M College. He has had 15 years' engineering experience, 11 years of which have been in teaching. His general fields of experience and present interests include instrumentation (temperature, acceleration, strain and stress), geophysical exploration, materials testing, and stress analysis and investigation. Specific projects upon which he has worked include the airborne magnetometer, Bomarc missile, and calibration of water integrating meters. He is a Registered Professional Engineer in Colorado.

Maxwell Parshall, Assistant Professor of Civil Engineering. and Meteorologist. He holds a B.S. degree in chemistry from Massachusetts Institute of Technology and a B.S. degree in civil engineering from Colorado A and M College. He has eight years' experience as an analytical chemist and ten years' experience in hydraulics laboratory work. The remainder of his experience has been in teaching. His principal interests are irrigation and hydraulics, and sanitary engineering. He is a Registered Professional Engineer in Colorado.

A. R. Robinson, Jr., Assistant Civil Engineer. He holds a B.S. degree in civil engineering from the State University of Iowa, and an M.S. degree in irrigation engineering from Colorado A and M College. He has one year of experience in field sedimentation studies and two years' experience in operation and maintenance of an irrigation project. He has been engaged in research on seepage, well hydraulics, drainage, water measuring devices and sand removal devices for the past six years. He has published several papers and reports in these fields. He is a Registered Professional Engineer in Colorado.

E. F. Schulz, Assistant Civil Engineer. He holds a B.S. degree in civil engineering and an M.S. degree in irrigation engineering from Colorado A and M College. He has had thirteen years' experience in engineering, 1½ years of this was in aerodynamics and flight, and five years was in fluid mechanics research. His primary interests are in ship and wave studies and in water supply hydrology. He has presented several papers and reports on ships and waves. He is a Registered Professional Engineer in Colorado.

R. D. Dirmeyer, Assistant Geological Engineer. He holds the degree of Geological Engineer from the Colorado School of Mines. He has had 11 years' experience in engineering geology work -- mostly associated with Federal irrigation projects. He initiated development of a method of reducing seepage from canals in earth by sedimenting water-transported colloids in the canal and has three years' comprehensive experience in this work. He is author of several papers on engineering geology and on canal lining.

R. W. Nelson, Collaborator, Agricultural Engineer, U. S. Department of Agriculture. He holds the degree of B.S. in agricultural engineering from the University of Idaho. He has three years' research experience in drainage of irrigated lands. He is currently interested in ground water hydrology and is working on a new type of analogue for seepage flow in a drain field.

E. V. Richardson, Collaborator, Hydraulic Engineer, U. S. Geological Survey. He holds a B.S. degree in civil engineering from Colorado A and M College and has taken graduate work at the State University of Iowa and at Colorado A and M College. His major field of interest is fluvial hydraulics and he has spent seven years in sediment investigations in Wyoming and Iowa. He is acting project leader for the U. S. Geological Survey on research in bed roughness in alluvial channels.

R. T. Shen, Assistant Research Engineer. He holds a B.S. degree in civil engineering and an M.S. degree in irrigation engineering from Colorado A and M College. He has had five years' experience in engineering research, including two years of technical editorship. He is a co-author of a research paper on heat transfer.

E. O. Plate, Assistant Research Engineer. He has completed the requirements for the degree of Diplom Ingenieur in civil engineering at the Technische Hochschule, Stuttgart, Germany. He came to the United States on a Fulbright and U. S. Government scholarship in the fall of 1954. He is currently working on his M.S. Thesis, Fundamental Research on Sand Wave Formations. He has two years' research experience in hydraulic model studies and sedimentation problems.

G. L. Smith, Assistant Research Engineer. He holds a B.S. degree in civil engineering from the University of New Mexico. He has completed the course work for an M.S. degree in irrigation engineering at Colorado A and M College. His experience includes six years as hydraulic engineer with the U. S. Engineer Corps on open channel flow problems, lock design, statistical analysis of flood frequencies on the main stem of the Mississippi River. His principal interest is in scour prevention and sedimentation.

B. Graduate Student Program

Average graduate enrollment in the Civil Engineering Department for the past four years has been 27. A total of 28 advanced degrees have been granted during this period. Nearly all of these students were specializing in some aspect of hydraulic engineering or fluid mechanics. Present graduate enrollment is 36, seven of whom have been admitted to study for the Ph.D. degree. In most cases graduate study has been made financially possible under a program of assistantships, mostly in research. At the present time, 19 graduate students hold such assistantships. Other graduate students receive financial assistance by direct part-time employment on Experiment Station and Federal co-operative projects. The graduate program is believed to be one of the major benefits of the research effort. Because of the large number of applications, admission is presently restricted. In addition, undergraduate students receive financial assistance through employment in the program.

The Master of Science degree requires a thesis involving original work; whereas the Master of Engineering degree may require a report, which is commonly a compilation and evaluation of current information on a specialized subject. A program leading to the degree of Ph.D. was initiated in 1952.

VIII

PUBLICATIONS AND THESES SINCE 1948

Sponsored project reports, published papers, bulletins, circulars, and student theses are a measure of the productiveness of a research team. Following are lists of the works of the research staff of the Civil Engineering Department during the period 1948 to 1956. These are presented in the following order: (A) Reports for Sponsored Projects, (B) Published Papers, (C) Bulletins and Circulars, and (D) Theses, Master's Reports and Dissertations. Classified research reports are omitted.

A. Reports for Sponsored Projects

1. Design of the Loup River Bed-Load Measurement Structure, by M. L. Albertson, prepared for U. S. Geological Survey, July, 1948.

2. Hydraulic Model Studies of Bhakra Dam, by M. L. Albertson, prepared for International Engineering Company, Inc., 1949.

3. Hydraulic Model Studies of Hirakud Dam, by M. L. Albertson, prepared for International Engineering Company, Inc., 1950.

4. Hydraulic Model Studies of Rihand Dam, by M. L. Albertson, prepared for International Engineering Company, Inc., 1950.

5. A Comparative Study of Momentum Transfer, Heat Transfer, and Vapor Transfer, Part I, Forced Convection, Laminar Case, by C. S. Yih, prepared for Office of Naval Research, Contract No 9 onr 82401, Report No. 1, September, 1950.

6. A Comparative Study of Momentum Transfer, Heat Transfer, and Vapor Transfer, Part II, Forced Convection, Turbulent Case, by C. S. Yih, prepared for Office of Naval Research, Report No. 2, June, 1951. Contract No. N9 onr 82401.

7. A Comparative Study of Momentum Transfer, Heat Transfer, and Vapor Transfer, Part III, Free Convection, by C. S. Yih, prepared for Office of Naval Research, Contract No. N9 onr 82401, Report No. 3, February, 1951.

8. Problems in Making Rain in the West, by T. H. Evans, Public Works, July, 1951.

9. Atmospheric Diffusion from a Point Source, by C. S. Yih, prepared for the Office of Naval Research, Contract No. N9 onr 82401, Report No. 4, August, 1951.

10. Laminar Heat Convection in Pipes and Ducts, by C. S. Yih and Jack E. Cermak, prepared for the Office of Naval Research, Contract No. N9 onr 82401, Report No. 5, September, 1951.

11. Natural Roughness in Artificial Channels, Report on Research completed under J. Waldo Smith Hydraulic Fellowship, by Arthur Willis Van't Hul, 1950-51. Rexographed.

12. Fluctuation Studies in Stilling Wells for Armco Metergate No. 101, by M. L. Albertson, prepared for Armco Drainage and Metal Products, Inc., 1951.

13. Atmospheric Diffusion from a Line and Point Source of Mass Above the Ground, by C. S. Yih, prepared for the Office of Naval Research, Contract No. N9 onr 82401, Report No. 6, April, 1952.

14. Determination of Wind Chill on a Life-Sized Clothed Copper Man, by J. E. Cermak, R. K. Thomas, M. L. Albertson, prepared for Quartermaster Corps, U. S. Army, Contract No. DA44-109-gm-584, June, 1952.

15. Laminar Free Convection Due to a Line Source of Heat, by C. S. Yih, prepared for the Office of Naval Research, Contract No. N9 onr 82401, Report No. 7, September, 1952.

16. On the Asymptotic Behavior of any Fundamental Solution of the Equation of Atmospheric Diffusion and on a Particular Diffusion Problem, by C. S. Yih, prepared for the Office of Naval Research, Contract No. N9 onr 82401, Report No. 8, September, 1952.

17. Temperature Distribution in the Boundary Layer of an Airplane Wing with a Line Source of Heat at the Stagnation Edge, Part 1, Symmetric Wing in Symmetric Flow, by C. S. Yih, J. E. Cermak and R. T. Shen, prepared for the Office of Naval Research, Contract No. NOnr-54401, October, 1952.

18. Temperature, Seepage and Turbulence as Factors Affecting Suspended Sediment Concentration, by J. R. Barton, and M. L. Albertson, prepared for the Bureau of Reclamation, Contract No. 12 R-19126, June, 1953.

19. Lake Hefner Model Studies of Wind Structure and Evaporation, Final Report, Part I, by J. E. Cermak and H. J. Koloseus, prepared for the Bureau of Ships, Navy Department, Contract NObsr 57053, November, 1953.

20. Development of Basin for Investigation of the Seaworthiness of Model Seaplane Hulls, by E. F. Schulz, prepared for the Bureau of Aeronautics, Navy Department, Contract NO as 52-1077-C, March, 1954.

21. Development of a Facility for Testing the Performance of Ship Hulls in Oblique Seas, by E. F. Schulz, prepared for the Bureau of Ships, Navy Department, Contract N9 onr 82403, March, 1954.

22. Tests of the Seaworthiness of Seaplane Hulls Having a High Length to Beam Ratio, by E. F. Schulz, prepared for the Bureau of Aeronautics, Navy Department, Contract No as 52-1077-c, May, 1954.

23. Lake Hefner Model Studies of Wind Structure and Evaporation, Final Report, Part II, by J. E. Cermak and H. J. Koloseus, prepared for the Bureau of Ships, Navy Department, Contract No. NObsr-57053, July, 1954.

24. Development of a Constant-Force Bottom Contour for Seaplane Hulls, by E. F. Schulz, prepared for the Bureau of Aeronautics, Navy Department, Contract No. NOas 52-332-c, November, 1954.

25. Vapor Transfer by Forced Convection from a Smooth, Plane Boundary, by J. E. Cermak and P. N. Lin, prepared for the Office of Naval Research, Contract No. N9Onr 82401. Report No. 9, January, 1955.

26. A Study of Transport of Sediment in Alluvial Channels, by J. R. Barton, prepared for the Corps of Engineers, Contract No. DA-25-075 Eng 2632, March, 1955.

27. Effect of Boundary Form on Fine Sand Transport in Twelve-Inch Pipes, by A. R. Chamberlain, prepared for Armco Drainage and Metal Products, Inc., June, 1955.

28. Report of Sediment Lining Investigations, Fiscal Years 1954 and 1955, by R. D. Dirmeyer, Jr., prepared for the Bureau of Reclamation, Contract No. 14-06-700-129, June, 1955.

29. Turbulent Diffusion of Momentum and Heat from a Smooth, Plane Boundary with Zero Pressure Gradient, by A. C. Spengos, prepared for Air Force Cambridge Research Center, Contract No. AF-19(604)421, February, 1956.

30. Report of Sediment Lining Investigations, Fiscal Year 1956, by R. D. Dirmeyer, Jr., prepared for the U. S. Bureau of Reclamation, Contract No. 14-06-700-1157, August, 1956.

31. Sediment Transport Through Pipes, by R. J. Garde, prepared for Armco Drainage and Metal Products, Inc., October, 1956.

32. Model Tests to Predict the Seaworthiness of Seaplane Hulls, by E. F. Schulz, prepared for the Bureau of Aeronautics, Navy Department, Contract Noas 54-908-c, January, 1957.

33. Model Tests with a Tanker in Oblique Seas, by E. F. Schulz, prepared for the David Taylor Model Basin, Navy Department, Contract N9onr 824(03), January, 1957.

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