INVESTIGATION OF DAM BREACH FLOODS

Engineering Research Proposal

Colorado State University
Fort Collins, Colorado

March, 1964

ENGINEERING RESEARCH PROPOSAL

INVESTIGATION OF DAM BREACH FLOODS

ENGINEERING RESEARCH CENTER
CIVIL ENGINEERING SECTION
COLLEGE OF ENGINEERING
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO

MARCH, 1964

CER64VMY17a

Engineering Research Proposal

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Nature of Study

The objectives of the proposed study are an experimental and analytical evaluation of existing methods and a development of new methods of computation in hydraulics of dam breaches. Three main problems are to be studied on large outdoor research facilities and on digital computers: (a) outflow hydrographs from sudden openings in impounded bodies of water; (b) progress upstream of the negative flood wave created; and (c) progress downstream in a natural channel of the positive flood wave created. The outdoor facilities consisting of a collapsible dam 20 to 25 feet high, an artificial reservoir about 850 feet long, and a 2700 feet long creek which connects this reservoir and College Lake will be used for the hydraulic experiments. Several digital computers are available for the necessary analytical and computational investigation. The proposed study will have two phases: (1) preliminary phase for which the support is being solicited by this proposal for the first year; and (2) main research phase which will last three to four years.

Principal Investigator:	V. M. Yevdjevich
Associate Investigators:	G. L. Smith W. F. Rowland
Amount:	$25,000 for preliminary or first phase of investigation.
Duration:	One Year
New or Continuing:	New

Engineering Research Center
Civil Engineering Section
College of Engineering
Colorado State University
Fort Collins, Colorado

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INVESTIGATION OF DAM BREACH FLOODS

1. Initial Information

During any sudden opening of impounded water, created intentionally or unintentionally, the released water results in two waves--a positive wave which travels downstream along the valley or channel (usually defined as dam breach flood as results of a dam breach), and a negative wave which travels upstream of the opening along the impounded body of water.

In studying any hydraulic phenomena which results from this sudden water release the general geometric characteristics of the opening, of its surrounding, as well as of the downstream channel and of the impounded body of water are assumed as known.

Three main hydraulic phenomena of sudden water release are usually studied and are worthwhile for further investigation: (1) Outflow hydrograph through the dam breach or any other sudden opening; (2) Negative wave which progresses and transforms itself upstream of the opening along the impounded body of water; and (3) Transformation of positive wave which travels downstream of the opening, usually along natural river channels and valleys.

All three phenomena have been studied extensively, and a substantial literature is available about them [see reference list, Exhibit No. 8]. However, only approximate methods of their computation actually exist, which in many cases do not give either a sufficiently accurate outflow hydrograph, or a sufficiently accurate following of progress and change with time of these two waves. This point of discrepancy between the actual knowledge about these three hydraulic phenomena and the need for a new knowledge and better methods of computation merits a more extensive explanation, and this problem will be discussed more fully in a later section.

Most of the methods available in the literature on these three problems are associated either with the regular shapes of conveyance structures and of bodies of impounded water, or are rough approximations when they are applied to channels and impounded bodies of water under natural conditions, especially to large reservoirs and sinuous river channels and river valleys.

The openings may be sudden or gradual. In the case of breaches of earth dams the progress of breach opening is slow in comparison with the sudden openings in concrete dams. The computation of outflow hydrographs is somewhat uncertain under conditions of gradual opening, if the ratio between the opening area and its shape is not known as a function of time. The outflow hydrograph is highly influenced by the negative wave which travels upstream, and in many cases, by the downstream submergence of the outflowing water through openings. Therefore, the outflow hydrographs from sudden openings are usually determined by approximate solutions only.

Large negative steep waves which are created by sudden openings in bodies of impounded water travel upstream, transform themselves, and reflect on banks in a complex way whenever a natural storage space is involved.

There are dozens of approximate flood routing methods for natural floods, both in literature and in practice. It may be stated, however,

that there are as many flood routing methods as there are practitioners. This statement, though it may be a little exaggerated, is given only to show that whenever an engineering approach tries to describe or compute the evolution in a complex hydraulic problem many methods in approximate forms have been both suggested and practiced. It is worthwhile to use any method in engineering work as long as the accuracy of results of the method can be evaluated or computed. Accuracy of results produced by many flood routing methods now being used cannot be evaluated, especially under different natural conditions of both wave shape and river and/or valley characteristics.

There is another important factor related to floods created by sudden openings. This is the shape resistance of natural valleys, particularly in the case of dam breaches. This resistance is of a special significance.

The best available method for computing flood movement along a river channel takes into consideration the river bed roughness which is determined from the available data on natural floods. Floods created by sudden openings in several cases (dam breaches particularly) exceed by several fold the maximum observed flood under natural conditions. Velocities of this sudden flood wave are, therefore, several times greater than velocities of natural floods. The shape resistance (contraction, expansion, bends, sudden changes, etc.) of river channels and especially of river valleys may be of greater significance than the bed roughness resistance of the river channel. So called "local resistance" becomes of a higher order magnitude than the surface bed roughness resistance. The shape resistance is understood here to include losses due to contraction, expansion, sudden changes of direction, creation of whirlpools in the enlarged part of the valley, bends, water drops, unusual obstacles in bed or at the banks, and so on. This "shape resistance," as called here, becomes much more important for floods from dam breaches than the surface roughness resistance in river beds and in valleys.

To prove this statement it is sufficient to build a hydraulic model of a sinuous and steep valley, and to create a dam breach wave at its top. The generated water wave climbs along the bends, breaks, and shows highly uneven cross section surface. After that experiment, one must ask himself how good the existing flood routing methods are; even how good are the basic mathematical equations which describe the unsteady river flow, under such conditions. A discrepancy must, therefore, exist between the actual methods of flood routing (used currently for dam breach flood routing) and the real physical aspects of dam breach waves.

There is clearly a need for more research along the lines of any one of the three main hydraulic problems outlined above.

2. Dam design and dam breach risks.

As the number of dams and reservoirs built in this country and in the world increases at an ever faster rate, the risks of future unintentional dam breach in a given time and region will thus increase with a geometric progression. The recent experience in several countries supports this statement, regardless of an ever better design and an ever safer construction of dams. The risk of intentional or accidental destruction or breaches of dams is always present.

There is another problem which increases the concern about the safety of dams. With the construction of more and more dams in a chain along a

river valley, a dam broken at the upstream part may endanger several dams below it and create a general dam breach reaction with more and more increasing severity of catastropic consequences downstream, especially in the case of dams which are earth-filled or rock-filled structures.

It seems a logical conclusion that the design of any dam should be accompanied by an extensive hydraulic study of what would happen downstream or even upstream in the case of dam breaches under different conditions such as: opening size; opening shape; opening position; time function of the opening; reservoir level at the time of breach; inflow into the reservoir at the time of dam breach; downstream channel conditions and water levels preceding the dam breach; and others. In this way, each project which has a special part included of the potential consequences of sudden openings under different conditions would show what risk is being taken in the case either an unintentional or an intentional sudden opening occurred in the impounded bodies of water. For the case of the dam breach only, the suitable methods for computations, especially oriented to be used in a digital computer, should be available. Since there is a large number of parameters with many possible combinations, only a method oriented to digital computers would be able economically to give all necessary information about dam breach phenomena. From the design point of view, the experimental and theoretical research which would result in sufficiently accurate computational methods for analysis of dam breaches and resulting flood wave generation would be a very beneficial step. However, the simple methods oriented to rapid, though approximate, computations may be necessary for the civil defense and general military needs as well as, in some cases, for reservoir operational purposes.

3. Main objectives of the proposed research project.

The main objectives of this proposal are to provide:

(1) A better understanding of hydraulic phenomena created by the sudden openings in impounded bodies of water in all three aspects: namely, outflow hydrograph, upstream propagation of negative waves, and downstream propagation of positive waves.

(2) A better understanding of the influence of type of opening, time of opening and surrounding geometric conditions on the outflow hydrograph from a breach or sudden opening.

(3) A study of the impact of shape resistance in river valleys on the propagation of positive and negative waves.

(4) A development of a set of methods for computation of hydraulic phenomena in propagation of waves produced by dam breaches, and other sudden opening in the impounded bodies of water, and particularly: (a) methods oriented to be performed by a digital computer; and (b) methods suitable to be performed by ordinary calculating devices.

(5) A study of the accuracy to be attach to each of the above methods of computation.

4. Reasons for the interest of Colorado State University in performing this research.

The Engineering Research Center of Colorado State University is interested in performing this research for the following reasons:

(1) To utilize efficiently the unusually favorable facilities which are now available in the outdoor hydraulic and hydrologic laboratory, as well as the indoor hydraulic and indoor fluid dynamics laboratory for this research project;

(2) The proposed project will fit into one of the intended specializations of the laboratory, as well as of staff members; the unsteady flow of water along the channels and conduits has been selected at the new Engineering Research Center as a specialty of the hydraulic and hydrologic research; some other activity in this field is being performed currently (free surface wave movement along storm drains);

(3) The project will help the graduate program of the University substantially and in three closely related directions: (a) It would provide a wide range of topics for M. S. and Ph. D. dissertations; (b) Funds of the project would support several graduate students by providing part-time work as they pursue their graduate studies; and (c) By working on this project the graduate students will obtain additional training in the basic and applied engineering research, regardless of the potential work on their dissertations.

(4) By performing this research, staff members of the Civil Engineering Department will keep abreast of science and produce new knowledge in this particular field of unsteady flow in river valleys.

(5) The Engineering Research Center of Colorado State University would be able to contribute substantially to the body of knowledge about the hydraulics of dam breaches, and about the risk involved from them.

5. Specific features of research facilities.

As the attached exhibits show, the new hydraulic research facilities at the Engineering Research Center represent a particularly favorable set-up for the type of research proposed by this research project.

This Center is described in a special number of "Colorado Farm and Home Research" under the title, "New Home for Engineering Research," July-August, 1963. This number of the bimonthly periodical is given as Exhibit No. 7.

The open-air hydraulic and hydrology laboratory is situated between the Horsetooth Reservoir and College Lake. The Horsetooth Reservoir belongs to the Bureau of Reclamation and is the last large storage reservoir in the Colorado-Big Thompson project. Open-air and two indoor laboratories are located a short distance from Soldier Canyon Dam. The general location of these facilities is shown in the pictures of Exhibit No. 1. The upper picture shows the main facilities, the lower picture the facilities for this research project.

An outlet in the south side of the dam provides, by gravity, the water supply to the laboratory. Furthermore, there will be available at all times a substantial rate of flow for both the outdoor and indoor laboratories. A water supply system was installed in 1963 from the outlet to the research facilities. The system consists of a 36-inch pipeline from the Soldier Canyon Dam outlet to the indoor hydraulic laboratory, and a 26-inch pipeline from that point to the center of the outdoor laboratory. This facility now supplies water to outdoor and indoor laboratories by gravity flow for the active research projects. The general plan of the actual outdoor and indoor laboratories is shown in Exhibit No. 2.

The University owns College Lake, (see Exhibit Nos. 1, 2, 3, 4, 7), which is a lake of 50-acre area, with useful storage capacity of about 500 to 700 acre-feet. Between the water outlet at Soldier Canyon Dam and the College Lake, there is a creek about 3500 feet long (Exhibit Nos. 1, 2, 3, 4, 5). This creek is canyon-like in its upper part, narrow valley-type in its middle part, and broad valley-type in its lower part, close to College Lake. This creek is available as part of the research facility for the study of dam breach problems and flood routing problems under natural conditions.

The upper part, about 850 feet long, is intended to be used as an artificial reservoir (Exhibit Nos. 3, 4, 5), or experimental, impounded body of water. The middle and lower parts of the creek (Exhibit Nos. 3 and 4) to the College Lake, about 2700 feet long, will be shaped in such a way that a dam breach wave can be not only studied but also conveyed without damage to other research facilities along the creek, and water then will be stored and flood wave attenuated in the College Lake.

This proposal has the following exhibits:

Exhibit 1. Upper picture. An air view photo of the area, with the main research facilities, either in existence or planned by this research proposal.

Exhibit 1. Lower picture. A photo of area viewed from the top of Soldier Canyon Dam with facilities either in existence or planned by this research proposal.

Exhibit 2. General map showing the location of research facilities.

Exhibit 3. A map of the area with the special emphasis on the facilities planned by this research proposal, with these facilities given by different colors.

Exhibit 4. A map of the facilities for this project, with a special emphasis on the cross sections along the creek.

Exhibit 5. A map of the facilities for this project with the special emphasis on the reservoir cross sections, and volume-stage relationship.

Exhibit 6. The graph of level fluctuation of Horsetooth Reservoir, from which water is to be drawn for this project.

Exhibit 7. No. 1, Vol. 14, number of Colorado State University, Experiment Station bulletin "Colorado Farm and Home Research" July-Agust, 1963, which describes the research facilities of the new Engineering Research Center at that time.

Exhibit 8. Reference list on the literature on hydraulics of dam breaches and the most closely connected problems.

These exhibits show the position and potentialities of the facilities planned and proposed by this research proposal in relation to other facilities, and the main features which enable this research project to be carried out efficiently.

6. The main concepts of research facilities.

Research facilities for this research project are conceived to be designed and constructed as follows:

(a) A collapsible type dam will be constructed across the creek, close to the indoor hydraulic laboratory, in such a way that it can impound the water upstream at a length of about 850 feet; the dam is to be so constructed that its individual parts, of different size and shape, as well as the total dam surface can be opened either suddenly or with a prescribed time opening regime, in order to simulate dam breaches or sudden openings of different characteristics.

(b) The impounded part of the creek as reservoir of about 10 to 12 acre-feet storage capacity (see Exhibit No. 5 and storage-stage relationship curve) will be shaped in such a way that the steep banks and negative wave reflections produced by dam breaches or sudden openings would not produce either bank slides or high erosion in the storage space.

(c) A water outlet from the main conduit supply, with a control valve (see Exhibit No. 3) will be installed in order to accomplish two objectives: first, to provide constant water flow regime through reservoir and downstream channel in order to determine properly the roughness and other flow conditions, or to keep a constant or variable regime flow through the reservoir prior to the sudden opening; and second, to produce a large flow through the reservoir during the experiments of a combination of natural floods and sudden openings in reservoirs.

(d) The channel between the collapsible dam and College Lake will be realigned in some places (Exhibit Nos. 3 and 4) by shifting it to the right bank of the valley in order to take the least possible space from other research facilities that are either in advanced state of development or are being planned for the near future.

(e) A levee built along the left bank of the creek (Exhibit Nos. 3 and 4) in order to confine the dam breach waves flood and prevent their overflow onto the low level land of the outdoor laboratory, especially the earth platform close to the College Lake, which is reserved for future research models of applied hydraulics.

(f) The channel between the collapsible dam and College Lake will be stabilized in an appropriate way against the erosion during the wave movement along it, if it is deemed necessary or feasible.

A decision either to fix the banks both of the storage reservoir upstream of the dam and the channel downstream from the dam to the College Lake or to leave it as it is now must be made for this project in the near future. The first alternative would insure that during experiments no appreciable erosion would take place, and that the geometric conditions and roughness would be

constant for all experiments. The second alternative would allow both erosion and the change of hydraulic characteristics during an experiment, and would require a survey of channel geometry, reservoir geometry and a check of flow resistance coefficients between experiments. In the first case, initial investment in fixing bed and banks is necessary. In the second case, the experiments would be closer to the conditions of potential natural cases, but would require constant survey of the channel roughness and of geometric characteristics between those experiments which produce appreciable erosion, change of bed, and sediment transport.

The dam height is planned for about 20 - 25 feet of impoundment. It will represent a large model scale with the nature, so that even a dam in nature 600 feet high would be represented at a geometric scale between the model and the prototype of about 1:30.

7. Survey and abstracting of basic literature on dam-breach waves.

The survey and abstracting of the basic literature on the unsteady free surface flow in open channels has been made by the principal investigator of this proposal, when he was working on an assignment with the United States Geological Survey, Washington, D. C., 1959-60. This work was done on a contract between U. S. Geological Survey and U. S. Soil Conservation Service. It was published under the title, "Flood Routing Methods, Discussion and Bibliography." That report contained 736 bibliographical entries, the major part of them have been abstracted, and the report had the following parts: (1) introduction, (2) general discussion of flood routing methods, or unsteady flow in channels and reservoirs, (3) chronological bibliography of references with abstracts, (4) cross index by authors, and (5) cross index by subjects.

In the years 1961 and 1962 this report was revised and supplemented with another 150 entries. It is now under printing in the Government Printing Office, and it is expected to be published as a U. S. G. S. Water Supply Paper, probably during the summer 1964.

The purpose of citing this extensive and very comprehensive work is to show in this proposal that the principal investigator and the future project leader responsible for the work is well acquainted with the problems of unsteady flow in open channels, including all available literature in nearly all major languages. Thus, the planned and proposed project will be based upon the actual knowledge of the subject matter, which is available for the hydraulics of sudden openings in reservoirs, and for the propagation of positive and negative waves along the natural channels and valleys.

A short list of the most pertinent references related to the hydraulic problems of dam breaches and resulting waves is given at the end of this proposal as Exhibit No. 8.

The report on "Flood Routing Methods, Discussion and Bibliography" is available in the libraries of most government agencies. It is out of print, and is not available any more from either the U. S. Geological Survey or the U. S. Soil Conservation Service, except on loan. The principal investigator has only one personal copy left. If any reviewers of this proposal cannot obtain a copy of this report from the library of his or some other agency, the principal investigator will be glad to send his copy on loan.

As soon as the U. S. G. S. Water Supply Paper containing this report is published, it will be sent to the potential sponsors.

The principal investigator has already carried out several studies, both in the field of computation of outflow hydrographs from breach dams as well as in the field of unsteady flow. To show that he is competent to guide the proposed research, as well as to contribute substantially to the better understanding of the problem and to develop new methods of computation of dam breach waves, the following five reports and articles are cited:

Yevdjevich, V. M., 1959, Analytical integration of the differential equation for water storage: U. S. Nat'l Bureau of Standards, Jour. of Research, B. Math and Math. Physic. 63B, no. 1, July-September, p. 43-52.

Yevdjevich, V. M., 1959, Effect of sudden water release on the reservoir free-outflow hydrograph: U. S. Nat'l Bureau of Standards, Jour. of Research, B Math. and Math. Phys., 63 B, no. 2, Oct.-Dec., p. 117-129.

Yevdjevich, V. M., 1959, Computation of the outflow from a breached dam U. S. Nat'l Bureau of Standards Report, no. 6473, July 31, p. 1-27.

Yevdjevich, V. M., 1960, Outflow hydrograph resulting from sudden release of ponded water through large opening: U. S. Geological Survey Report.

Yevdjevich, V. M., 1961, Unsteady free surface flow in a storm drain (general and analytical study): Engineering Research Center, Colorado State University, Fort Collins, Colorado, June 1961, Report CER61VMY38, p. 1-76.

The first four entries are the result of the research the principal investigator has done for the Army Map Service, Washington, D. C., working on a contract between the U. S. National Bureau of Standards or U. S. Geological Survey and the Army Map Service.

Chief Engineer, Department of the Army, Washington 25, D. C., has compiled an engineer intelligence guide entitled, "Computation of Outflow of Breach Dams," which has used extensively the above first four cited works by the principal investigator.

During the analytical study for developing the suitable methods of computation of outflow hydrographs from breached dams the principal investigator has come to a conclusion that substantial progress in this field cannot be accomplished without further systematic research activities, both theoretical (analytical) and experimental, under close conditions to those dam breaches which occur or may occur in nature. As a result of his experience, theoretical work carried out, as well as from the recent studies and experimental work by many authors, the principal investigator is convinced that this proposal refers to a very worthwhile subject matter of sufficient importance to be pursued in the immediate future. He is convinced that this research proposal will be very beneficial and will produce useful practical computational methods, as well as general knowledge of the problem.

8. General approach to research activities.

This proposal is giving only the general line to be followed in the research activities. Two distinct phases of the research are desirable. The preliminary phase would be related to problems investigation, design of experimental research facilities, design of particular instrumentation, and to a detailed research program planning. The main phase will be related to the

construction of research facilities and instruments, the research activities, and the general interpretation of the research results.

This research is planned to be approached from three aspects of problems involved: (1) as basic research when it can contribute substantially to the understanding of hydraulic phenomena; (b) as applied research, which will lead to the practical procedures and methods of computation; and (c) as supplying the guidelines for the design criteria.

Engineering Research Center of Colorado State University is very well equipped for the basic research. Besides the collapsible dam and the experimental creek transformed in the research facilities, two other main research facilities are already available in the laboratories. First, a large circulating tilting flume 200 feet long, 8 feet wide, 4 feet deep with the adjustable slope from 0 to 3 percent, and a maximum flow of 100 cfs is in the final stage of construction and will be operational this year. Second, a large pipe, 3 feet in diameter, 825 feet long, movable on the supports at a hillside from 0 to 4 percent, and with a maximum flow up to 100 cfs is now in the operation for the study of storm floods moving with the free surface flow through large drains. Both of these large facilities can be adjusted to be used in both basic and applied research as might be needed. Besides, the large hydraulic indoor laboratory as well as the fluid mechanics laboratory may help the probject to solve any particular or detailed problem which may be encountered during the research activities on the main facilities.

Engineering Research Center has the necessary equipment and instruments, and a digital paper punch recorder with 20 channels will also be available this year for the recording of flood waves.

Engineering Research Center has access to several computers depending upon the problem at hand from the slow computer IBM 1620 through IBM 7090, IBM 7094, to the fast computer CDC 3600 on very convenient conditions.

This proposal is conceived in such a manner that the basic and applied research will be carried out at the CSU Engineering Research Center completely. The application of the results obtained for the design criteria and for the design computation should be left to the sponsoring agency or agencies but with the full help and cooperation of the CSU staff which will be working on this project.

The preliminary phase of the project is conceived to be finished in nine months or a year from the moment the project starts. This phase is planned to accomplish the following objectives.

1. To summarize the actual status of the knowledge in hydraulics of dam breaches (or of any sudden openings in large bodies of impounded water), as well as to show the actual techniques available for the computation of progress along natural valleys of both positive and negative waves created by these sudden openings. This part of the study will be based (but greatly enlarged) on the work already done by the principal investigator in 1959-62.

2. To define clearly the hydraulic problems which have to be studied in all three parts of the project: (a) hydraulics of the outflow hydrographs from different openings; (b) movement and transformation of the negative waves which travel upstream; and (c) movement and transformation of the positive waves which travel downstream of the breach along the natural channels (especially

including the "shape resistance" problem). A detailed plan of research activities will result, and it will be a guide for the research activities of the following three to four years program.

3. Design of the collapsible dam to meet the different conditions of experimental program and to perform various research objectives with sudden openings. As of now, the dam is conceived to be made of a steel frame, with bolted, but small parts, arranged in such a way that the various shapes and sizes of openings can be produced. At the same time the mechanism for creating the sudden openings will be studied and designed. To record all necessary variables during that process of sudden openings, the appropriate devices will also be investigated and designed.

4. The available simple methods of computation of outflow from breached dams (especially the U. S. Corps of Engineers' Engineer Intelligence Guide: Computation of outflow from breached dams) will be used to determine the maximum expected flood waves downstream from the dam under various conditions in order to design the levee (dike) along the creek to contain the flood wave inside the natural channel and the levee and convey the water to the College Lake without damage.

5. The lateral movement and corrections of creek channel and the flood entrance into College Lake will be designed.

6. Banks inside the future reservoir and along the channel and levee, then the inflow and control of the water into the reservoir and similar problems will be also studied and appropriate constructions designed.

7. The main instruments to be used will be studied and designed, particularly how to be assembled for the main future phases of the research, and a study of instruments for recording flood waves along the channel, reservoir, and the outflow hydrograph will be made.

8. A general program for the research activities for three to five years duration will be the main result from this first phase.

9. An estimate of manpower necessary, of professors, other staff members, consultants, graduate students, programmers, shop workers, and others will follow.

10. An estimate of the cost for the research facilities and research for 3 - 4 years will follow the study, design, and planning of structures and works to be carried out.

The result of the first phase of this research project will be such as to enable any sponsoring agency to make decision about supporting the further research based on the expected benefit and the expected cost of the research activities to follow.

The first part of the main phase will cover the period of construction of facilities; purchase, assembly and calibration of instruments; calibration of channels and reservoirs as it concerns their bed roughness and their shape roughness; a detailed survey of the natural channel; and similar. Concurrently with this field work, the theoretical and analytical work will be

pursued, and particularly techniques will be sought for integrating the available mathematical equations for description of various hydraulic problems to be investigated, especially by finite differences method and digital computers.

The second part of the main phase will consist of experiments in the outdoor research facilities, paralleled by computer studies of problems studies, and particularly of the same waves observed or simulated in the outdoor hydraulic experimental facilities. The first approach in this phase is to check out how well the physical aspects of the outflow hydrograph of sudden openings, the physical aspect of the progress of positive and negative flood waves are described by the best mathematical equations actually available, as well as of the methods of integrating them. The modification of the existing mathematical equations, or derivation of new ones will be carried out in such a way as to provide closer approximations to the physics of waves which propagate under natural conditions.

The final results of this main research phase is to develop a set of methods for the computation of dam breach flood waves. Each method should suit various requirements for reliability, going from the most accurate methods to the most simplified methods. These last methods should be performed without a digital computer by ordinary calculating devices.

The first part of the main phase of the project will probably last about a year, or the second year of the project, and the second part of the main phase will take two to three years, which will depend upon difficulties and problems encountered in these research activities.

9. Manpower for this research project.

The following staff members are actually available or will be available by September, 1964, to carry out this research project for the preliminary phase, or the first year, and then to continue the main phase of the project:

(1) Dr. Vujica M. Yevdjevich, as principal investigator and project leader;

(2) Mr. George Smith, assistant for the design of facilities and instruments, construction and experimental work;

(3) Mr. Walter F. Rowland, assistant for the literature survey, study of detailed research program, and the research activities;

(4) Mrs. Lois Niemann, programmer;

(5) Graduate students in the number necessary as the work will demand.

Consultants and advisors for any aspect of the project will be available on the campus: (1) Dr. Daryl B. Simons and Dr. J. E. Cermak, professors, for special hydraulics and fluid mechanics problems; (2) Mr. Charles Britton, professor, for instrumentation; (3) Dr. John W. N. Fead for the design of the collapsible dam; (4) Dr. Herbert Bailey for the numerical methods of integration of differential equations and similar problems. Several other staff members in the laboratory, who are specialized in particular problems connected with this research project in any way, will be available as advisors or collaborators.

Several advisors outside Colorado State University staff, like Dr. Robert Dressler, Professor Eugene Isaacson, and others, are available for consultation.

10. Main information about the first three staff members:

Vujica M. Yevdjevich - Graduated in 1936 from the University of Belgrade, Civil Engineering Department. Graduated in 1939 from the School for Hydraulic Engineers, Grenoble, France. Obtained doctor's degree in 1955 from Serbian Academy of Science, Belgrade. From 1946-1957 he has been teaching and involved in the research in hydrology and hydraulics in Yugoslavia. Since February, 1958, he has been working in the United States on different research projects with the U. S. National Bureau of Standards and U. S. Geological Survey. In September, 1960, he became associated with Colorado State University. He is now Professor in Civil Engineering, and Professor-in-charge of Hydrology Program. Four of his books and about 50 of his papers and reports have been published.

G. L. Smith - Assistant Civil Engineer, and Assistant Professor of Civil Engineering, received his B. S. in civil engineering from the University of New Mexico in 1947, his M. S. in irrigation engineering from Colorado State University in 1957. He spent one year at the University of Iowa doing graduate work in hydraulics and fluid mechanics. During the period from 1949-1955 he was employed by the Corps of Engineers at Vicksburg, Mississippi as a hydraulic engineer and as a hydrologist, of both model and prototype flood control structures for the Mississippi River and development of statistical methods for determination of flood frequencies on the main stem of the Mississippi River. His experience with the Corps of Engineers and Colorado State University includes research on many hydraulic structures and problems.

Walter F. Rowland - Assistant Civil Engineer and Assistant Professor of Civil Engineering. Ph. D. from University of California should be obtained by August, 1964. By September, 1964, he will join the staff of CSU Engineering Research Center.

11. Budget for the preliminary phase and the first year of the project.

A. Salary of staff members, graduate students, advisors and secretary		
1. V. M. Yevdjevich - 2 months at $1588 plus 6% retirement	$3,366.00	
2. G. L. Smith - 3 months at $831.82 plus 6% retirement	2,645.19	
3. W. F. Rowland - 4 months at $909.18 plus 6% retirement	3,854.54	
4. Lois Niemann - 1/2 month at $400.00	200.00	
5. M. S. graduate student - 1/2 time basis for nine months at $225.00	2,225.00	
6. Ph. D. graduate student - 1/2 time basis for six months at $300.00	1,800.00	
7. Advisors - one month total	1,500.00	
8. Secretarial help - 2 months at $386.00 plus 6% retirement	909.05	
Total Salaries and Annuities		14,909.05
B. Expenses		
1. Purchase of different reports and publications	300.00	
2. Telephone tolls	100.00	
3. Two trips to Washington, D. C. for the consultation with sponsoring agency	500.00	
4. Duplication of the final report	300.00	
5. Photographic services	100.00	
6. Model of small collapsible dam	300.00	
7. Experiments with small collapsible dam	721.52	
Total Expenses		2,621.52
C. Indirect Costs		
Overhead - 50.1% of salaries and wages	7,469.43	
Total Indirect Costs		7,469.43
TOTAL COST		$25,000.00

12. Rough estimate of the budget for the main phases and successive years.

It is difficult to estimate now, without the work accomplished as planned for the preliminary phase of the project, what will be the cost and approximate time duration of the main phase. However, a rough estimate is necessary for a general insight into the magnitude of the project.

A.	First part of the main phase, or second year of the project with construction of facilities, purchase and assembly of instrumentation, and analytical research	$85,000
B.	Second part of main phase, or third year, experimental and analytical research work	60,000
C.	Second part of main phase, or fourth year, experimental and analytical research (but analytical research predominating)	50,000
D.	Final work, fifth year, with final reports	30,000
	TOTAL ESTIMATE FOR THE PROJECT	$250,000

Colorado State University Engineering Researach Center is using military surplus material extensively in its work for government agencies (vehicles, instruments and similar items). If this will continue also for this project, a substantial cost reduction can be realized in the total cost of the project.

It should be stressed here, that in any complex hydraulic or hydrologic problem the great efforts, time, and means are needed in order to obtain substantial results and to advance new knowledge by both the basic and applied research.

INFORMATION CONCERNING INSTITUTION SUBMITTING PROPOSAL

A. The contracting (grantee) agency is the Colorado State University.

B. Colorado State University is an agency of the STATE OF COLORADO and enjoys exemption from tort liability.

C. The address of the business office is FORT COLLINS, COLORADO.

D. The officials authorized to sign and submit proposals and to negotiate contracts are the DIRECTOR AND CONTRACTS AND GRANTS ADMINISTRATOR, COLORADO STATE UNIVERSITY RESEARCH FOUNDATION, FORT COLLINS, COLORADO; Telephone Area Code 303 491-6355.

E. The PRESIDENT OF COLORADO STATE UNIVERSITY OR HIS AUTHORIZED REPRESENTATIVE is authorized to sign contracts or acknowledge grants.

STATEMENT ON SOLICITING

We hereby certify that we have not employed or retained a company or person (other than a full-time employee) to solicit or secure this contract (grant) and agree to furnish information relating thereto as requested by the sponsor's cognizant officer.

March 27, 1964
Date

V. M. Yevdjevich
Vujica M. Yevdjevich
Principal Investigator

March 27, 1964
Date

D. B. Simons
Acting Chief, Civil Engineering
Research Section

March 27, 1964
Date

James R. Grace
James R. Grace
Contracts and Grants Administrator
Colorado State University Research
Foundation

EXHIBIT 8

MAJOR REFERENCES ON HYDRAULIC PROBLEMS OF DAM BREACHES

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