SELECTION OF CREST CONTROL FOR SPILLWAYS
TECHNICAL REVIEW STAFF
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Memorandum
Assistant Commissioner - Engineering and Research

Denver, Colorado
December 19, 1979 1531

Chief, Technical Review Staff

Paper on Selection of Crest Control for Spillways

At your request, the Technical Review Staff has prepared the subject paper which reviews the policy and selection criteria of WPRS. This paper provides general information on selection of spillway crest control, especially for embankment dams, and makes recommendations on preparation of guidelines. The paper has been reviewed by Division of Design and Division of Research, and their comments have been used.

Copies are enclosed for a limited distribution to segments of the ACER organization having an interest in the subject.

E. T. Scheich

Enclosures

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ROBERT B. JANSEN
ASSISTANT COMMISSIONER
ENGINEERING AND RESEARCH

selection of the type of spillway or combination of types may also be critical. In this regard, the use of an auxiliary spillway may significantly reduce the cost of accommodating the inflow design flood.

The economics of spillway selection should be recognized as a potentially important ingredient to total project economics and as site specific as are other factors.

Factors Involved in Selection of Spillway Gates

In the previous section, crest control was covered to the extent that the basic question of gating of crests was discussed along with the factors which should influence the selection of gated and ungated spillways. This section addresses the question of gate selection. Some of the same factors apply to selection of gates as to selection of spillway type.

All types of spillway crests can be gated. Certain common types of gates can be used for any type of crest. Other gate types are only suited to a particular type of crest. Limitations and special considerations are covered in this section. Primary consideration is given to spillway gates but it should be recognized that outlet works, while not considered to be spillways by the WPRS, are frequently used for making flood releases from a reservoir and in some cases are the main flood release provisions. Whenever large outlets are required for reservoir evacuation, diversion during construction, or for making project required releases to the river, they should be used, if adequately reliable, along with the spillways in routing floods through the reservoirs.

The most common types of spillway gates used by the WPRS are radial and fixed wheel. Drum and caterpillar gates have been used on older spillways but not in the past thirty years. A ring gate was used on the shaft spillways at Owyhee and Hungry Horse Dams, and a bascule gate is proposed for addition to the Dickinson Dam spillway crest. The ring gates are now considered undesirable because of low dependability and high maintenance costs. Radial gates have been used almost exclusively in recent WPRS spillway designs. A notable exception is the spillway for Morrow Point

Dam which use fixed-wheel or wheel-mounted gates. Top seal radial gates are used for large river outlet works such as Fontinelle, Twin Buttes, Sanford, and Davis Dams.

For flood outlets, the most common types of regulating gates and valves used are: high-pressure slide gates, hollow-jet valves, jet-flow gates, and top-seal radial gates. Of limited use have been fixed-cone valves, sleeve valves, and needle valves.

Selection of a particular type of gate for a spillway depends on the geometry of the crest structure, hoisting equipment that can be economically provided, potential ice problems, and the economics of the total installation. As with flood outlets, high reliability is of the greatest importance. Possible settlement of the crest structure and wall deflections are extremely important considerations affecting gate reliability.

Automatic Controls for Gated Spillways

Spillway gates can be operated automatically by geared screw lifts, hydraulic hoists, by electrical hoists with wire ropes or chains connected to the gates, or hydraulically using floats and wire ropes. Only hydraulic float-operated and electric hydraulic chain and wire rope hoists have been used for large spillway gates.

Geared screw lifts are used on many small- or medium-sized gates and valves. Hydraulic hoists have been widely used to supersede geared screw lifts for large high-head gates due to the higher hoist capacities, design simplicity, ease and flexibility of control, and operating reliability of hydraulic hoists. The electrical operating systems can be used in conjunction with geared screw lifts or hydraulic hoists. All systems can be operated manually or automatically to meet operating requirements.

The use of automatic controls can reduce some human errors in gate operations. Consequently, automatic control systems are often preferred at locations where the qualifications of available operating personnel are unknown or questionable. A fully automatic hydraulic control system with float operated gates may be desirable where a reliable power supply is not available. It is important to have a backup or auxiliary system to operate gated spillways under unexpected or emergency conditions. It is also important that all the gates and operational systems be adequately inspected, tested, and maintained to ensure proper operation and long service life. Periodic testing of the automatic system is very important. Present WPRS criteria for automation of spillway gates is presented in a report of the Design Research Team for Automation of Spillway Gates dated June 24, 1971, and approved by Chief, Division of Design, on July 22, 1971. A copy is included as appendix B.

Automatic controls for gated spillways have been developed over a period of many years. Early designs were very simple and many had inherent deficiencies that led to abandonment. Later designs of the general type now used have been modified to increase reliability.

The two general types of automatic controls used by the WPRS are the hydraulic actuated float type and the water contact electric type. In the first, a controlled inflow and outflow causes water to rise or fall in float wells, which in turn raises or lowers the floats which are connected to counterweighted gates by some form of linkage. The second type consists of a probe which makes contact with water in a control well reflecting reservoir elevation which actuates electric operated hoists.

The early designs of hydraulic operated systems introduced reservoir water directly into a float well causing the gate to open. Control was usually provided by a gated outflow pipe which made it possible to control the level of water in the float well, thus it was possible to lower the gate. The serious deficiency in this system was the outflow gate which either had to be preset or manually operated during a flood. This weakness made excessive releases possible if the outflow gate opening was too small or prevented the gate from opening if the gate setting was too large. In addition to the problem of properly controlling the float well water level, there is a tendency with this type of operation for the gate to overtravel. These deficiencies led to abandonment of some early automatic systems.

The deficiencies of the early systems were corrected in later designs by making the inflow-outflow relationship entirely automatic and sensitive enough to avoid the overtravel problem. The initial attempts to accomplish this resulted in mechanical connections and moving parts which brought into question the reliability of the automatic system. Problems associated with a movable control weir and recommended modifications are discussed in detail in a January 8, 1959 memorandum to Chief Designing Engineer from Chief, Mechanical Branch, and included in appendix C. Efforts of others outside the WPRS had similar shortcomings in the early stages of development.

The latest WPRS designs of hydraulic float-operated systems have no moving parts but rather use a system of fixed orifices to control inflow and outflow which give the desired flexibility. The hydraulic automatic float-operated system of gate control also adds redundancy to the gate operation by providing for manual hydraulic operation which can be used when the normal electric hoist system is inoperable because of power failure. To add this feature, control valves are located in the water piping in such a way as to bypass the automatic controls.

The electric contact automatic control system for gated spillways is normally used to control the operation of electric hoists for making flood releases. The system is comprised of a water supply pipe and intake located in the reservoir at a distance not affected by the drawdown caused by gate operation and a small control well at the spillway gate structure, a probe used to make electric contact with the water in the control well, and electric circuits to the gate hoists.

Advantages and Disadvantages of Gated Spillways

Whether a gated spillway should be used for a given project depends on the site specific conditions, the type of dam (concrete or embankment),

SELECTION OF CREST CONTROL FOR SPILLWAYS

by

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United States Department of the Interior

Water and Power Resources Service

Engineering and Research Center

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SELECTION OF CREST CONTROL FOR SPILLWAYS

INTRODUCTION

This report was prepared at the request of the Assistant Commissioner - Engineering and Research to provide general information on selection of type of crest control that is appropriate for various site specific conditions and in particular, but not restricted to, embankment dams. The report reviews the policy and selection criteria of the WPRS (Water and Power Resources Service), other Government agencies, selected consulting firms, and the USCOLD (U.S. Committee on Large Dams).

The general question of selection of spillways is addressed to introduce factors that influence the choice of spillway type without regard to the crest control features. Other factors are discussed in detail that are important to the question of providing gate control of spillway releases. The advantages and disadvantages of gated spillways are identified and an assessment of risk is made for specific WPRS dams which were selected because of major differences in site specific conditions and operating requirements. Recommendations are made with respect to guidelines for selection of the type of spillway contol and developing WPRS policy.

The definition of a spillway is not uniform throughout the world. The WPRS restricts the term to the hydraulic feature that is designed to release flood water at the surface or near the surface of a reservoir. For releases of flood water at lower levels of the reservoir, the term floor outlet or river outlet is used. In literature of the International Commission on Large Dams, the terms surface spillway, midlevel spillway, and bottom level spillways are used.

GENERAL DISCUSSION OF SPILLWAY SELECTION

Spillways can be classified in many ways with respect to type. The WPRS terminology will be used in this report. Because of the wide variety of combinations that are in common use, a simple classification is presented in the following:

By use	- Service, auxiliary, emergency
By type of waterway	- Open chute, tunnel, conduit
By type of inlet	- Straight crest, curved crest, side channel, double side channel (duckbill, bathtub), shaft (morning glory), grade sill
By type of crest control	- Gated, ungated (free overflow)
By terminal structure or energy dissipator	- Hydraulic jump stilling basin, impact basin, plunge pool, flip bucket

These classifications are frequently used to describe or identify the type of spillway and a description may use all five classification elements in the order listed above. For example, a description could be: a service spillway with open chute, straight gated crest, and hydraulic jump stilling basin.

Each element making up a complete spillway is selected to best meet site conditions and project purposes and an optimum combination is finally determined.

Factors Involved in Selection of General Type

1. Site conditions. - Geologic and topographic conditions are important to spillway selection and sometimes dictate the location, type, and components of a spillway. These site conditions may limit the surcharge elevation and volume, the spillway dimensions, the need for and type of energy dissipator, and the suitability of a particular type of spillway at the given site, etc. These site conditions and their impacts on the selection of spillway types are given below.

The capability of a spillway crest to pass a given amount of inflow design flood depends on crest length and head, and whether or not the crest is gated. Topography may limit the alternatives that can be considered for a crest structure and other features. This is especially true for canyon sites where a gated spillway may be the only viable choice. Other topographic settings may impose other limitation on alternatives. For example, topography may limit the maximum storage level which in turn may limit the surcharge storage and head on the crest. Thus, in a flat land setting, a gated crest may be necessary to avoid a free overflow crest of extreme length and exorbitant cost.

Geologic conditions limit spillway alternatives in ways similar to those imposed by topographic conditions. Foundation strength limits the size of structure that can be used which may eliminate use of high gates. Inferior abutment rock may make use of tunnels and other underground construction unattractive. Where space limitations and erosion resistant rock exist in combination, a concrete dam with a free fall spillway may be a satisfactory and economic choice. Space limitations also suggest use of side-channel and morning glory type crest structures.

A chute-type spillway may be appropriate where site topography and subsurface foundation conditions require that the discharge flow be carried by an open waterway to the river channel downsteam from the dam.

Tunnel and conduit spillways are often used for damsites in canyons with steep abutments where open chutes may require excessive excavation, or where a shaft or morning glory type crest control has been selected.

These few examples are only representative of the many geologic and topographic conditions which may influence or even dictate the selection of a spillway type and combination of elements.

2. Hydrologic and hydraulic factors. - One of the most important factors to be considered in the design of a spillway is its capability to safely

pass an inflow design flood. This capability depends not only on the reservoir storage volume, maximum allowable water surface elevation, and the hydraulic efficiency of the spillway, but also on our ability in flood forecasting and spillway operation. The runoff characteristics of a drainage basin, the storage capacity of the reservoir, and the frequency of releases through the spillway should be considered in balancing the costs of increasing the dam height and other related items against the costs of using a more expensive spillway or a more sophisticated operation.

Different types of spillways have different hydraulic efficiencies of discharging flow under different hydraulic conditions. A morning glory or shaft spillway can discharge its maximum capacity at relatively low heads thus making this type of spillway ideal where maximum spillway outflow is to be or can safely be limited, but this type is objectionable where a reserve capacity for unanticipated inflow is desired. An auxiliary spillway in conjunction with a service morning glory spillway can be used to advantage, where site conditions permit, to pass flood inflows of low frequency of occurrence above the design capacity of the morning glory inlet.

The effectiveness of reservoir operation, especially with gated spillways, depends on our ability to forecast the magnitude and characteristics of the inflow design flood. Where the forecasting ability is insufficient or unreliable, or where the "lag time" is short, an ungated spillway is usually preferable to a gated spillway. Under conditions where a gated spillway is the only viable choice, redundancy should be included in the design, such as alternative operating provisions and automatic controls. Auxiliary and emergency spillways should be considered where site conditions are favorable in order to provide for uncertainties of the inflow design flood and operating reliability of gated spillways.

3. Project objectives and flexibility requirements. - The project objectives of a reservoir should be considered in the selection of spillway type. Where a reservoir is used for recreational purposes, or where shoreline development precludes large increases in reservoir level

during flood events, a gated spillway may be advantageous. However, an ungated spillway is indicated for a short-lived reservoir such as one which will fill with sediment after a short service life and the spillway must pass the full flow of the river in a safe manner. In order to fully utilize the maximum head available for hydropower generation for a given height of dam (or because of topographic limitations), gated spillways are preferred to avoid or to reduce surcharge storage. Gated spillways have operational flexibility that can be utilized to economic advantage as well as for safety considerations. For example, gated spillways have the capability of making large advance releases when inflow can be accurately predicted, can be used to make flood control releases, and with respect to safety, can be used for rapid evacuation of storage during an emergency, especially if high gates are used.

4. Hazard potential. - The most important factor which should be considered in spillway type selection is safety or hazard potential. Minor overtopping of a short duration can be tolerated for a concrete dam but not usually for an embankment dam. Hazard potential is related to the location of a dam, our ability in flood forecasting, and other factors such as seismicity of the site. For a dam constructed above a population center, the spillway and its associated operating equipment such as gates, hoists, and control devices have to be designed to safely pass the inflow design flood under the most severe conditions that can be reasonably assumed. Ungated spillways are usually preferred for embankment dams above population centers because of the possibility of having equipment failure or operational errors during floods. If a gated spillway is required for compelling reasons, a high level of redundancy should be included in the design to provide an acceptable safety margin.

5. Operation and maintenance. - Operation and maintenance factors should be given careful consideration in the selection of a spillway type. Ungated spillways are less dependent on operation and maintenance than are gated spillways. Where a gated spillway is selected for an embankment dam, it is usually desirable for gates to operate automatically and where electric power is used for manual and/or automatic operation of

the hoists, a secondary stand-by power supply should be provided and operating instructions should be clearly written and provide for frequent inspection, maintenance, and testing. It is good practice for designers to select the least complicated equipment and operational plans practicable. This is especially important where the quality and reliability of personnel involved in the operation and maintenance plans are uncertain. This would mainly apply to work in developing foreign countries or work outside the control of the WPRS.

6. Economics. - The preceding factors involved in selecting a type of spillway for a dam were concerned with physical conditions at the site, hydrologic influences, project objectives, consideration of operation and maintenance, flexibility, and hazard potential. Reference was made to cost in terms of being prohibitive or excessive, or indirectly with respect to hydropower in terms of fully utilizing head potential. It was also emphasized that safety of structures is a primary consideration that must not be compromised to reach other objectives. Construction of dams is not entirely risk free but those responsible for the designs must be satisfied that the risks are acceptable.

Economic considerations are a valid part of good engineering practice and may become critical ingredients in determining the value of engineering works to a client. In WPRS work, the benefits must at least equal the cost, and selection of a spillway may be a critical element of cost. It is not uncommon for a spillway to equal or exceed the cost of a dam.

In cases where spillway costs may become a dominant factor, the relationship between reservoir storage potential and flood volume may be the key to favorable or unfavorable economics. In such cases, optimization of spillway capacity and surcharge storage, which is reflected in dam, rights-of-way, and relocation costs, may be extremely important in the overall economics of the project. When it is recognized that the economics of accommodating the inflow design flood is of major importance, selection of the type of spillway or combination of types may also be critical. In this regard, the use of an auxiliary spillway may significantly reduce the cost of accommodating the inflow design flood.

The economics of spillway selection should be recognized as a potentially important ingredient to total project economics and as site specific as are other factors.

Factors Involved in Selection of Spillway Gates

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The most common types of spillway gates used by the WPRS are: radial, fixed wheel, drum, and caterpillar. A ring gate was used on the shaft spillways at Owyhee and Hungry Horse Dams, and a bascule gate is proposed for addition to the Dickinson Dam spillway crest. Radial gates have been used almost exclusively in recent WPRS spillway designs. A notable exception is the spillway for Morrow Point Dam which use fixed-wheel or wheel-mounted gates. Top seal radial gates are used for large river outlet works such as Fontinelle, Twin Buttes, Sanford, and Davis Dams.

For flood outlets, the most common types of regulating gates and valves used are: high-pressure slide gates, hollow-jet valves, jet-flow gates, and top-seal radial gates. Of limited use have been fixed-cone valves, sleeve valves, and needle valves. All of the foregoing gates and valves are considered to be highly reliable if properly installed and maintained.

Selection of a particular type of gate for a spillway depends on the geometry of the crest structure, hoisting equipment that can be economically provided, potential ice problems, and the economics of the total installation. As with flood outlets, high reliability is of the greatest importance. Possible settlement of the crest structure and wall deflections are extremely important considerations affecting gate reliability.

Automatic Controls for Gated Spillways

Spillway gates can be operated automatically by geared screw lifts, hydraulic hoists, by electrical hoists with wire ropes or chains connected to the gates, or hydraulically using floats and wire ropes.

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The use of automatic controls can reduce some human errors in gate operations. Consequently, automatic control systems are often preferred at locations where the qualifications of available operating personnel are unknown or questionable. A fully automatic hydraulic control system with float operated gates may be desirable where a reliable power supply is not available. It is important to have a backup or auxiliary system to operate gated spillways under unexpected or emergency conditions. It is also important that all the gates and operational systems be adequately inspected, tested, and maintained to ensure proper operation and long service life. Periodic testing of the automatic system is very important. Present WPRS criteria for automation of spillway gates is presented in a report of the Design Research Team for Automation of Spillway Gates dated June 24, 1971, and approved by Chief, Division of Design, on July 22, 1971. A copy is included as appendix B.

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The deficiencies of the early systems were corrected in later designs by making the inflow-outflow relationship entirely automatic and sensitive enough to constantly provide a closing tendency, thus solving the overtravel problem. The initial attempts to accomplish this resulted in mechanical connections and moving parts which brought into question the reliability of the automatic system. Problems associated with a movable control weir and recommended modifications are discussed in detail in a January 8, 1959 memorandum to Chief Designing Engineer from Chief, Mechanical Branch, and included in appendix C. Efforts of others outside the WPRS had similar shortcomings in the early stages of development.

The latest WPRS designs of automatic control systems have no moving parts but rather use a system of fixed orifices to control inflow and outflow which give the desired flexibility and natural tendency for the gates to close rather than a tendency to continue to open. The hydraulic automatic float-operated system of gate control also adds redundancy to the gate operation by providing for manual hydraulic operation which can be used when the normal electric hoist system is inoperable because of power failure. To add this feature, control valves are located in the water piping in such a way as to bypass the automatic controls.

The electric contact automatic control system for gated spillways is normally used to control the operation of electric hoists for making flood releases. The system is comprised of a water supply pipe and intake located in the reservoir at a distance not affected by the drawdown caused by gate operation and a small control well at the spillway gate structure, a probe used to make electric contact with the water in the control well, and electric circuits to the gate hoists.

Advantages and Disadvantages of Gated Spillways

Whether a gated spillway should be used for a given project depends on the site specific conditions, the type of dam (concrete or embankment), and the objectives of the project. The advantages and disadvantages of using gated spillways are discussed below.

1. Flood control effectiveness. - Detailed comparisons of flood control effectiveness of gated and ungated spillways were made by Hathaway [1]*. Two plans of gate operation were studied by Hathaway. Plan A requires gates be opened at the rate necessary to maintain an outflow rate equal to the reservoir inflow rate until all gates are fully opened. Plan B requires gates be raised in unison by small increments and limit the raise to a predetermined surcharge curve. Hathaway's comparison showed that an ungated spillway has lower maximum rate of discharge and a lower rate of discharge increase than a gated spillway operated under either plan A or B. The advantages of lower discharge and lower increase in discharge with an ungated spillway is even greater during floods of smaller magnitude than the inflow design flood.

However, if the spillway is designed to pass a given peak discharge, the storage volume required by a gated spillway is less than an ungated spillway. Thus, the use of gated spillways has an economic advantage provided the greater rate of release would not have adverse downstream impact.

2. Operation and maintenance. - Constant attendance and regulation of the control device by an operator is highly desirable for gated spillways even where automatic controls are provided and should be mandatory where automatic controls are not provided. They also require regular maintenance and repairs, whereas ungated spillways are basically free from these problems.

3. Discharge capacity. - For a given spillway crest length and maximum allowable water surface elevation, a gated spillway can pass higher discharge than an ungated spillway. Sometimes this advantage

* Numbers in brackets refer to references at the end of report.

is the determining factor in selecting a gated spillway instead of an ungated spillway in order to meet limitations on spillway crest length and maximum surcharge elevation.

4. Emergency evacuation. - An ungated spillway cannot draw down water below its crest. The ability for a gated spillway to draw down water from the top of the gate to the spillway crest is an advantage where emergency evacuation to reduce critical head is a matter of concern.

5. Project objective and flexibility. - Gated spillways are often preferred for flood control reservoirs because the gates can make a wide range of flood control releases in addition to having a large capacity for releases larger than the flood control limits. Large flood outlets can sometimes be avoided to reduce project cost. If a reservoir is designed for hydropower generation, a gated spillway is usually preferred due to its ability to take advantage of a given dam height by maintaining a higher and more constant head because surcharge storage can be avoided or be reduced. For a multiobjective reservoir (especially recreation, fish and wildlife uses), a gated spillway is often chosen due to its capability of maintaining a more constant water level during flood inflows.

6. Data requirements. - Because gated spillways may require constant control when in operation, they require more hydrologic and hydraulic data to ensure proper operation. Reliable hydrologic data are essential to accurate flood forecasting. A gated spillway cannot be operated to its maximum capability without reliable means of accurate flood forecasting.

7. Hazard potential. - The maintenance and operation free nature of an ungated spillway reduces the hazard potential associated with improper maintenance and operation of a spillway. However, if a gated spillway is properly maintained and operated, it could have an added

safety factor over an ungated spillway due to the flexibility in operation of a gated spillway, such as the greater capability of preflood season drawdown.

8. Economics. - While improved economics should not be at the expense of safety, economic considerations often determine whether a spillway should be gated or not. The ability for a gated spillway to pass greater discharge at a given combination of spillway length and maximum allowable water surface elevation are among the advantages of using gated spillways from an economic point of view. The flexibility in operation of a gated spillway is an attractive factor to be considered in maximizing the overall economic benefits of a multiobjective reservoir.

CURRENT PRACTICE

The general guidelines on the selection of spillway type for Federal dams are given in "Federal Guidelines for Dam Safety" [2]. It states that "Spillways * * * should be selected to meet the site specific purposes of the project. For a drainage area with short concentration time combined with reservoir storage capacity that is small relative to the flood volume, especially for embankment dams, the spillway should usually be uncontrolled." Although the general guidelines suggest the use of uncontrolled or ungated spillways wherever they are feasible, the final selection on spillway type should fully take into consideration the site specific conditions and purposes of the project.

It should be emphasized that the selection of a spillway type to satisfy site specific purposes of the project should not be at the expense of safety especially where a dam is constructed above a populated community. The policy recommended by the USCOLD (U.S. Committee on Large Dams) [3] is that "The policy of deliberately accepting a recognizable major risk in the design of a high dam simply to reduce the cost of the structure has been generally discredited from the ethical and public welfare standpoint, if the results of a failure would imperil the lives and lifesavings of the populace of the downstream flood plain. Legal and financial capability to compensate for economic losses associated with major dam failures are generally considered as inadequate justifications for accepting such risks, particularly when severe hazards to life are involved."

In addition to the above guidelines and policy, the following quotations from "Design of Gravity Dams" [4], published by the WPRS, list general factors which should be considered in the selection and design of spillways. "In determining the best combination of storage and spillway capacity to accommodate the selected inflow design flood, all pertinent factors of hydrology, hydraulics, geology, topography, design requirements, cost, and benefits should be considered. These considerations involve such factors as (1) the characteristics of the flood hydrograph; (2) the damages which would result if such a flood occurred without the dam; (3) the damages which would result if such a flood occurred with the dam in place; (4) the damages which would occur if the dam or spillway should fail; (5) effects of various dam and spillway combinations on the probable increase or decrease of damages above or below the dam (as indicated by reservoir backwater curves and tailwater curves); (6) relative costs of increasing the capacity of spillways; and (7) use of combined outlet facilities to serve more than one function, such as control of releases and control or passage of floods.

"A comprehensive study to determine alternative optimum combinations and minimum costs may not be warranted for the design of some dams. Judgment on the part of the designer would be required to select for study only the combinations which show definite advantages, either in cost or adaptability. For example, although a gated spillway might be slightly cheaper overall than an ungated spillway, it may be desirable to adopt the latter because of its less complicated construction, its automatic and trouble-free operation, its ability to function without an attendant, and its less costly maintenance.

"Where site conditions are favorable, the possibility of gaining overall economy by utilizing an auxiliary spillway in conjunction with a smaller service-type structure should be considered. In such cases the service spillway should be designed to pass floods likely to occur frequently and the auxiliary spillway control set to operate only after such small floods are exceeded."

Similar factors are also considered by the U.S. Army Corps of Engineers and other agencies in their selection and design of spillways.

The integrity and safety of a spillway not only depends on engineers' sound judgment of the above factors in their designs but also on operational procedures used especially for gated spillways. The general procedures used by the U.S. Army Corps of Engineers are given in Engineering Manual 1110-2-3600 "Reservoir Regulation" [5]. It states that "* * * insofar as practicable, reservoirs controlled by gated spillways should be designed and operated to accomplish the following objectives during periods when the reservoir is filled or nearly filled:

(1) Peak rates of reservoir release during damaging floods should not exceed peak rates of the corresponding floods that would have occurred under runoff conditions prevailing before construction of the reservoir.

(2) The rate of increase in reservoir releases during a significant increment of time should be limited to values that would not constitute a major hazard to downstream interests."

Essentially the same operational policies are used by the WPRS and other agencies with dam construction responsibilities.

Table 2 lists the gated spillways for embankment dams constructed by the WPRS.

Table 3 lists embankment dams that do not have service spillways but rely on flood outlets or emergency spillways or both.

Table 1, prepared by G. A. Hathaway [1] in 1951, summarizes the type of 100 spillways constructed under the supervision of the Army Corps of Engineers.

Table 1. - Spillway serviceability classifications*

Serviceability classification of spillway	Type of dam	Number of spillways in each class — Type of control — Gated	Number of spillways in each class — Type of control — Ungated (i.e., free over-flow)	Total	Number of spillways with stilling basins
Service	Earthfill	5	19	24	19
	**Concrete-earthfill	13	3	16	10
	Gravity concrete	10	6	16	13
	Concrete arch	0	3	3	0
	Subtotal	28	31	59	42
Limited service	Earthfill	3	22	25	0
	Rockfill	0	1	1	0
	**Concrete-earthfill	1	2	3	0
	Subtotal	4	25	29	0
Emergency	Earthfill	0	5	5	0
	Subtotal	0	5	5	0
Combination of service and limited service or emergency	Earthfill	2	3	5	0
	**Concrete-earthfill	2	0	2	0
	Subtotal	4	3	7	0
Grand total		36	64	100	42

* Compilation based on review of plans for 100 larger dams constructed under supervision of the Corps of Engineers, Civil Works, Department of the Army.

** Valley section of concrete (incorporating spillway and outlet facilities) and earth embankments connecting to abutments.

Table 2. - Gated spillways for WPRS embankment dams

Name of dam	No.	Gates size (ft)	Type	Discharge total (ft³/s)	Type of conveyance	Date of completion
1 Agency Valley	3	18x17	Radial	10,000	Chute	1935
2 Alamogordo (Sumner)	3	45x21	Radial	56,000	Chute	1937
3 Alcova	3	25-8x40	Fixed wheel	55,000	Chute	1938
4**American Falls	5	44x25	Radial	87,000	Gravity crest	1977
5 Angostura	5	50x30	Radial	247,000	Gravity crest	1949
6 Anderson Ranch	2	25x22	Radial	10,000	Chute	1950
7 Blue Mesa	2	25x33.5	Radial	33,700	Tunnel	1966
8 Boca	2	19x16	Radial	8,000	Chute	1939
9 Boysen	2	30x25	Radial	20,000	Chute	1952
10 Bradbury (Cachuma)	4	50x30	Radial	159,000	Chute	1953
11 Bull Lake	3	29x11	Radial	11,000	Chute	1938
12 Caballo	2	50x22.5	Radial	33,200	Chute	1938
13 Cascade	2	21.20	Radial	12,000	Chute	1948
14 Choke Canyon	7	49.2x23.7	Radial	251,766	Chute	UC
15 Cle Elum	5	37x17	Radial	45,700	Chute	1933
16 Davis	3	50x50	Fixed wheel	214,000	Gravity crest	1950
	2	22x19	Top seal radial	43,400	Gravity crest	1950
17 Deer Creek	2	21x20	Radial	12,000	Chute	1941
18 Echo	4	18x17	Radial	15,000	Chute	1931
19 El Vado	1	36x24	Radial	24,700	Chute	Rehab. 1955
20 Enders	6	50x30	Radial	200,000	Chute	1951
21 Glenn Elder	12	50x21.8	Radial	178,000	Chute	1966
22 Granby	2	21x20	Radial	11,500	Chute	1950
23 Gray Reef	2	35x20	Radial	20,000	Chute	1961
24 Green Mountain	3	25x22	Radial	25,000	Chute	1943
25 Guernsey	1	50x50	Stoney	50,000	Chute	1937
	2	64x14.5	Drum	25,800	Shaft, tunnel	1937

Table 2. - Gated spillways for WPRS embankment dams (cont.)

	Name of Dam	Gates No.	Gates size (ft)	Type	Discharge total (ft^3/s)	Type of conveyance	Date of completion
26	Hyrum	3	16x12	Radial	6,000	Chute	1935
27	Jackson Lake	17	8x7-10	Radial		Gravity crest	1911
		2	10x7-10	Radial	8,690 total	Gravity crest	1916
28	Kachess	1	50x8	Radial	4,000	Chute	1936
29	Lovewell	2	25x20	Radial	35,000	Chute	1957
30	McKay	6	20x10	Radial	Original 10,000 increased to 27,000	Side channel Chute	1979
31	Minidoka	4	10x12	Top seal radial	7,900	Gravity crest	1913
	plus uncontrolled crest with 5-ft flashboards				99,700 total	Gravity crest	
32	Moon Lake	2	24x16	Radial	10,000	Chute	1938
33	Norton	3	30x36.35	Radial	94,600	Chute	1964
34	Olympus	5	20x17	Radial	21,200	Gravity crest	1949
35	Palisades	2	20x50	Radial	48,500	Tunnel	1957
36	Palmetto Bend	12	35x22.61	Radial	176,000	Chute	UC
37*	Patillas	3	30x33.38	Radial	79,000	Chute	1974
38	Pineview	2	12x22	Radial	10,000	Chute	1937
39	Rye Patch	2	18x17	Radial	20,000	Chute	1936
40	Scoggins	2	19x20.5	Radial	14,000	Chute	1975
41	Shadow Mountain	2	18x20	Radial	10,000	Chute	1946
42	Tiber	3	22x38	Radial	57,800	Chute modification	1980
43	Tieton	6	65x8	Drum	38,000	Chute	1925
44*	Toa Vaca	3	30x33.38	Radial	78,000	Chute	1972
45	Trenton	3	42x30	Radial	133,000	Chute	1953
46	Unity	2	24x16	Radial	10,000	Chute	1938
47	Vallecito	3	37x19	Radial	30,000	Chute	1941
48	Webster	3	33.3x39.5	Radial	138,000	Chute	1956

* Designed by WPRS for Puerto Rico Water Resources Authority.
** Designed and constructed by Bechtel.

Table 3. - Examples of WPRS embankment dams without service spillways

	Name of dam	Completion date	Total storage (acre-feet)	Spillway
1	Soldier Creek	1973	1,106,500	None
2	Steinaker OS*	1961	37,200	Emergency only
3	Wasco	1959	13,100	Emergency only
4	Helena Valley OS	1958	10,600	None
5	Haystack OS	1957	6,600	None
6	Crescent Lake	1956	86,000	Emergency only
7	Stubblefield	1954	16,200	Emergency only
8	Vermejo No. 2	1954	2,900	Emergency only
9	Vermejo No. 13	1954	5,000	Emergency only
10	Carter Lake OS	1952	112,200	Section of canyon rim 2 ft lower than dams
11	North & Dry Falls Dams (Banks Lake)	1951	1,275,000	None
12	Jackson Gulch OS	1949	10,000	None
13	Horsetooth Reservoir OS	1949	151,800	250 ft of dike 4 ft lower than embankment
14.	Mary's Lake OS	1949	900	None
15	Wickiup	1949	187,300	Emergency with earth plug
16	Long Lake OS	1948	65,000	Emergency only
17	Willow Creek (Montana)	1911, 1941	32,400	Emergency only
18	Pishkun Dikes OS	1931, 1940	46,700	None
19	Deer Flat	1908, 1938	190,000	Emergency only
20	Midview OS	1937	5,800	Emergency only
21	Soldier Meadows OS	1923	2,000	None
22	Reservoir A	1907, 1922	3,000	None
23	Nelson Dikes	1915, 1922	85,500	None

*OS = Offstream

Besides Federal agencies, private consulting firms also design and construct major spillways. Generally speaking, private firms follow the aforesaid guidelines and policies with varying degrees of modifications to satisfy the requirements of their clients. There are very few published documents which state private firms policies on the selection of spillway type. It appears that they are more inclined to the use of gated spillways than Federal agencies in order to maximize the economic benefit, especially where hydropower is a factor of concern. For example, among the 26 spillways designed by Harza Engineering Company [6] with initital year of operation between 1942 and 1985, only three are ungated.

CASE STUDIES OF GATED SPILLWAYS USED FOR MAJOR WPRS DAMS

The spillways for four major WPRS embankment dams have been selected for special study and evaluation. Each dam has site specific conditions such as hydrology, geology, topography, and hazard potential, and project requirements that are different from the others. The four dams are: Norton, Palmetto Bend, Bradbury, and Blue Mesa.

The study evaluates the major factors that are present at each dam and those that were actually considered in making the spillway selection. Performance information is also presented and a rough assessment is made of current risks. From this assessment, suggestions are made which will enhance the safety of these dams with respect to accommodating major floods.

Bradbury Dam

Bradbury Dam, completed in 1953, is located on the Santa Ynez River about 25 mi northwest of Santa Barbara, California. The dam was constructed as a zoned earthfill embankment approximately 3,350 ft long and has a height of 206 ft between dam crest and streambed elevations. The impounded reseroir has a capacity of 210,000 acre-ft at top of active storage. The reservoir surface area is 3,090 acres and has a length of approximately 7 mi. The reservoir is located in a broad open valley with gentle sloping shorelines. There are several residential and commercial developments along the river downstream from the dam.

The spillway has a gated crest with a reinforced concrete chute with four 50- by 30-ft radial gates as shown in figure 1. It has a discharge capacity of 159,000 ft^3/s. The gates are controlled by a float-operated hydraulic automatic system with manual override. Electric power for manual operation is supplied by commercial power with an engine generator as a backup auxiliary power source. Twenty-four-hour attendance is required when the spillway is in operation. The gated spillway is capable of evacuating the top 30 ft of the reservoir or about 40 percent of the active capacity of the reservoir. The river outlet works has a capacity of 350 ft^3/s. The Tecolote Tunnel inlet is located about 3 mi upstream from the dam and 90 ft below the maximum conservation water level in the reservoir. It has a nominal capacity of 100 ft^3/s. This tunnel can also be used in conjunction with the spillway and river outlet works to evacuate the reservoir.

The inflow design flood is a rainstorm flood having a peak of 183,000 ft^3/s and a 3-day volume of 330,000 acre-ft. Reservoir drainage area is about 420 mi^2.

Because of the large flood volume and the relatively small storage capabilities, surface area of 3,090 acres at top of active storage, a large capacity spillway was necessary. A comparable ungated spillway using the same reservoir rise as the gated design, 10.5 ft, would have required an uncontrolled crest length of 1,500 ft. A structure of this magnitude would have been extremely difficult to locate at this site because of unfavorable topography. In addition, elimination of the gated spillway would have required the inclusion of a large outlet of reservoir evacuation to replace the lost gated spillway capacity. Rough cost comparisons at 1953 prices show that project cost with an ungated spillway would be increased by approximately $3,500,000.

The automatic gate operation feature and economic considerations were the prime factors considered when selecting the final design scheme.

For the first time since construction of the Bradbury Dam, the reservoir was filled during the heavy storm in April 1958. While the automatic

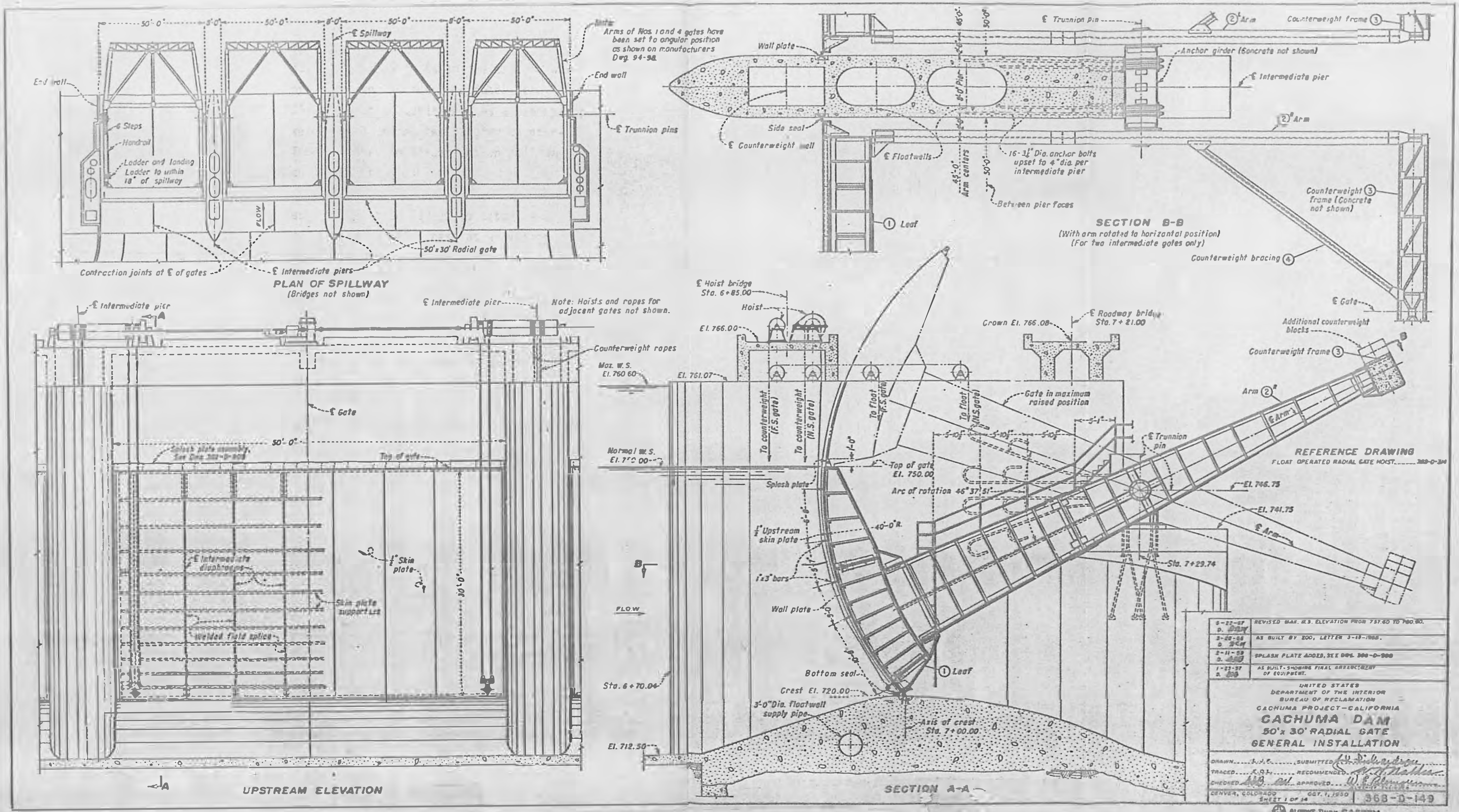

Figure 1. - Bradbury (Cachuma) Dam Spillway

controls have been satisfactorily tested many times in the dry, it was discovered that with 6 inches of water running over the gates, the controls were inadequate for fully automatic operation. As an emergency measure, 6,500 lb of sandbags were placed on the two hanging counter-weights of one of the gates. The following modifications on spillway gate controls were made after the incident:

1. Fix one control wier crest at elevation 750 ft to establish the maximum storage level and the second weir crest at elevation 757.75 to establish the maximum surcharge level.

2. Modify the overriding feature to enable an operator to bypass the automatic control if necessary.

3. Add a 1-ft splash plate to the top of each gate to permit full storage at elevation 750 ft without danger of overtopping the gates.

After these modifications, gates were operated satisfactorily during the 1962, 1965, and 1969 flood releases.

Norton Dam

Norton Dam, completed in 1965, was constructed on Prairie Dog Creek approximately 2 mi upstream from Norton, Kansas. The dam is an embankment dam approximately 6,500-ft long and has a height of 101 ft between streambed and crest elevation. The reservoir has a capacity of 136,700 acre-ft which includes an exclusive flood control pool of 100,000 acre-ft. The reservoir, which is located in a broad open valley with gentle sloping shorelines, has a surface area of 6,740 acres and is approximately 10 mi long.

The spillway is a gated reinforced chute with three 30- by 36.35-ft radial gates as shown in figure 2. It has a capacity of 94,600 ft^3/s. The gates are controlled by a float-operated hydraulic automatic system

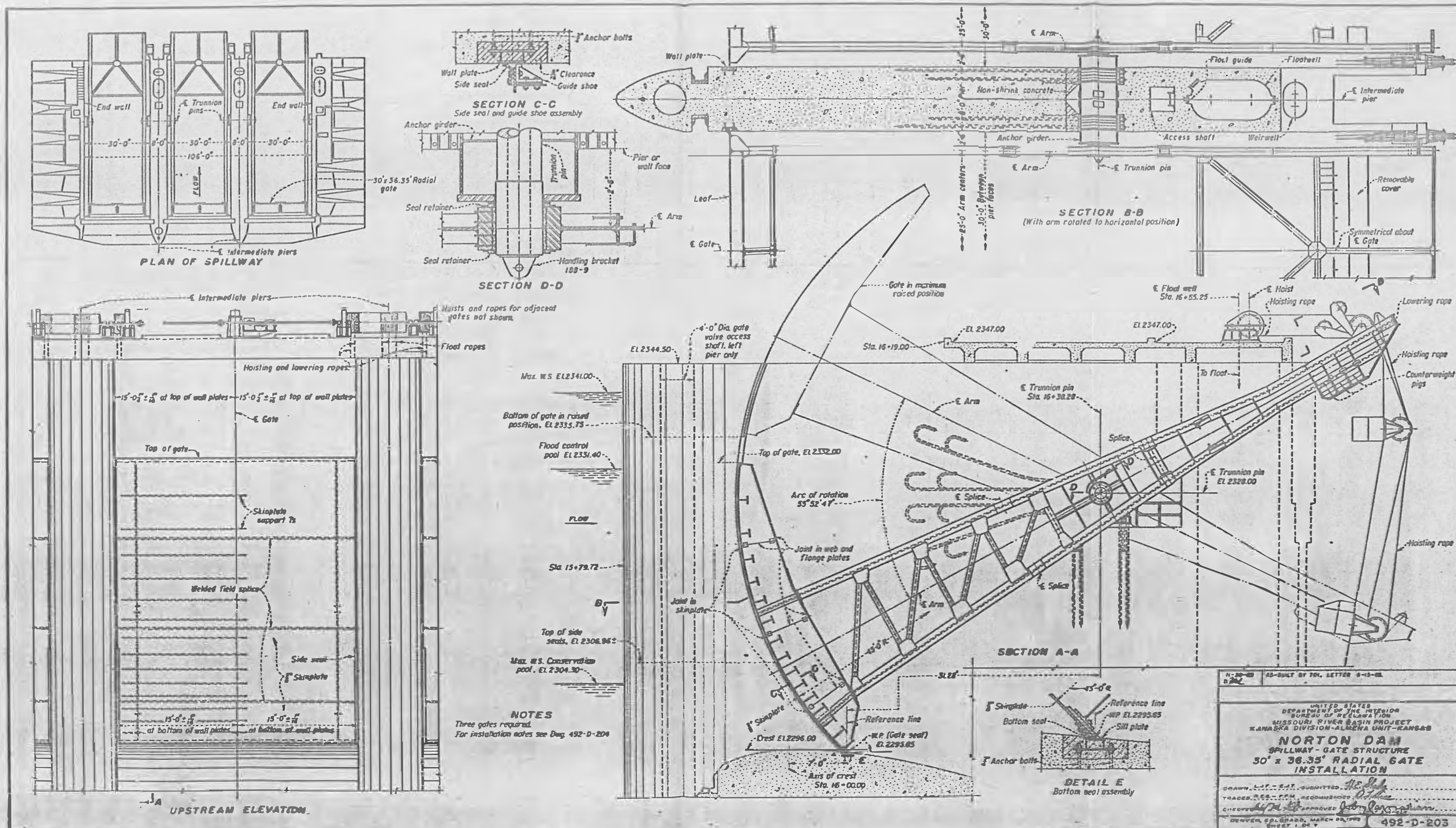

Figure 2. - Norton Dam Spillway

with manual override. The river outlet has a capacity of 330 ft^3/s. The dam will be attended on a 24-hour basis whenever more than one-half of the exclusive flood control capacity is filled.

The inflow design flow is the result of a rainstorm on a drainage area of 712 mi^2. The flood has a peak of 172,000 ft^3/s and a 4-day volume of 284,800 acre-ft. Due to high cost of right-of-way and relocating of a railroad track, it was desirable to limit the maximum water surface elevation of the reservoir as much as practical. Approximately 8 mi of track relocation was needed for construction of the dam as designed. Any higher water surface would have required additional track construction. In addition, the railroad company was concerned about exceeding the maximum feasible grade for the track as designed. Any increase in water surface elevation would have compounded the problems associated with the railroad relocation. A comparable ungated spillway would have required an uncontrolled crest length of 660 ft.

Elimination of the gated spillway would have required the inclusions of a large flood control outlet. Rough cost comparisons at mid-1965 prices show that project cost with an ungated spillway would be approximately \$9,300,000 while the cost for construction of the project as designed was \$5,700,000. To store the inflow design flood without the use of any spillway would have required approximately 30 ft additional height to the embankment. This is unacceptable in view of the maximum feasible railroad grade and the high cost of right-of-way.

The automatic gate operation features and the inclusion of a large flood control pool, along with the economic considerations, were prime factors used when selecting the final design scheme.

Periodic inspections of the spillway and gates indicate that they are all in excellent operational condition.

Blue Mesa Dam

Blue Mesa Dam, completed in 1966, was constructed on the Gunnison River approximately 30 miles downstream from Gunnison, Colorado. Blue Mesa Dam is a rolled earth embankment approximately 770 ft long and has a height of 340 ft between streambed and crest elevations. A powerplant with a capacity of 60,000 kW is located approximately 800 ft downstream of the dam centerline in the river channel. The primary purposes of the project are hydroelectric power generation and flood control. Except for the downstream Morrow Point and Crystal Reservoirs, there are no developments in the rugged canyon for many miles.

The reservoir is located in a broad open basin with steep canyon walls on the left side and generally gentle slopes on the right side. The reservoir has a total storage capacity of 941,000 acre-ft, of which 748,000 acre-ft is used as joint use storage. The reservoir surface area at top of active storage is 9,200 acres and has a length of about 26 mi.

The maximum water surface was limited because of environmental considerations, specifically the inundation of prime resort developments between the reservoir headwaters and the city of Gunnison and the worsening effects of river ice jams due to reservoir backwater. Extension and relocation of a U.S. highway and a railroad were required.

The inflow design flood is a snowmelt flow with a peak of 38,800 ft^3/s, a 60-day volume of 2,477,000 acre-ft, and a 30-day volume of 1,737,000 acre-ft.

The spillway is a gated concrete lined tunnel with two 25- by 33.5-ft radial gates as shown in figure 3. It has a capacity of 33,700 ft^3/s. This capacity combined with the river outlet capacity of 5,100 ft^3/s is capable of passing the peak of the inflow design flood thus resulting in no surcharge storage. The gate controls do not have automatic operating features. In case of power failure, one turbine unit of the powerplant shall be started to provide power for operating the gates. The gate can be operated manually at the dam or can be operated remotely at the

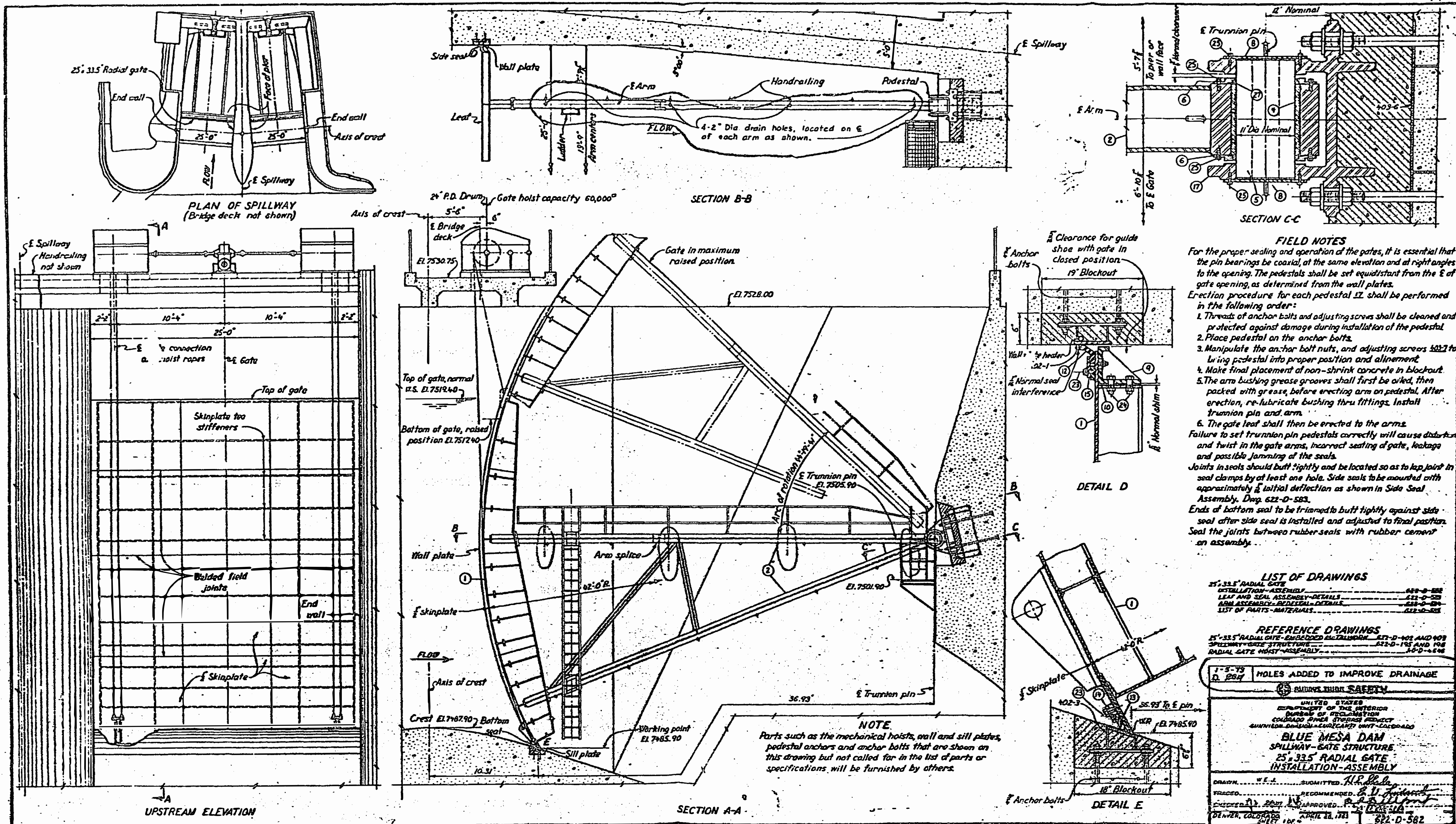

Figure 3. - Blue Mesa Dam Spillway

Montrose Control Center where reservoir water surface and gate openings data are telemetered. In addition, an alarm system was included in the designs to alert operators should a sudden reservoir rise go unnoticed. Spillway gates are protected against ice formation by an automatic ice prevention system.

The topographic setting of Blue Mesa Dam severely limited the designer options for selection of spillway types. Although the reservoir storage capacity is large, the volume of the flood is such that storage of the flood is not practical. The narrow and deep canyon walls that make up the dam abutments dictated that tunneling was the only option for a conveyance system. An economic comparison was made between the existing gated tunnel spillway and an uncontrolled morning glory entrance tunnel spillway. The cost increase using the ungated plan, including 9.5 ft increase in dam height, came to approximately $3,000,000.

The large joint use reservoir pool along with the gated spillway afford excellent reservoir operation flexibility for accommodating snowmelt floods and for providing flood control benefits. Since the safe channel capacity below the series of dams is 15,000 ft^3/s, controlling of large floods are of great value.

Prime factors considered in the selection of final designs included the limitation on maximum water surface elevation, the topographic setting of the damsite, the project purpose of hydroelectric power generation and flood control, and the economic advantages.

The spillway discharged for several days during June and July of 1970 with maximum discharge reaching 3,500 ft^3/s. The gates were operated satisfactorily. Some minor damages on the tunnel during the flood release were repaired.

Palmetto Bend Dam

Palmetto Bend dam is currently being constructed on the Navidad River about 7 mi south of Edna, Texas, and approximately 15 mi inland from the Gulf of Mexico. There are no residential or commercial developments between the dam and the gulf. The embankment dam is approximately 8 mi long and has a height of 55 ft between streambed and crest elevations. The impounded reservoir has a capacity of 170,300 acre-ft at top of active storage, elevation 44. The reservoir surface area is 10,370 acres and has a length of about 35 mi. Topographic considerations limit the maximum reservoir water surface at this site to an elevation of about 47.0

The spillway is a gated, reinforced concrete chute with twelve 35- by 22.61-ft radial gates as shown in figure 4. The capacity of the spillway is 176,000 ft^3/s. The gate controls are float operated electric automatic with manual override. The energy source is from a commercial powerline with two engine generators as backup.

The inflow design flood is a rainstorm flood having a peak of 193,000 ft^3/s and a 10-day volume of 770,000 acre-ft. Because of the limited surcharge height, 3 ft, and the large volume of the flood compared to the reservoir capacity, it was necessary that the spillway have sufficient discharge capacity to pass approximately the flood peak. These constraints dictated the use of a gated spillway.

A comparable ungated spillway would have required a crest length of 9,500 ft which could not be economically justified nor would such a design be practicable. In addition, the gated spillway is capable of evacuating the top 50 percent of the reservoir. If an ungated spillway were used in the designs, a much larger river outlet would have been needed.

Topographic limitation at the damsite, reservoir evacuating capability, and economic advantages were the prime factors considered in the final selection of spillway type for the Palmetto Bend Dam.

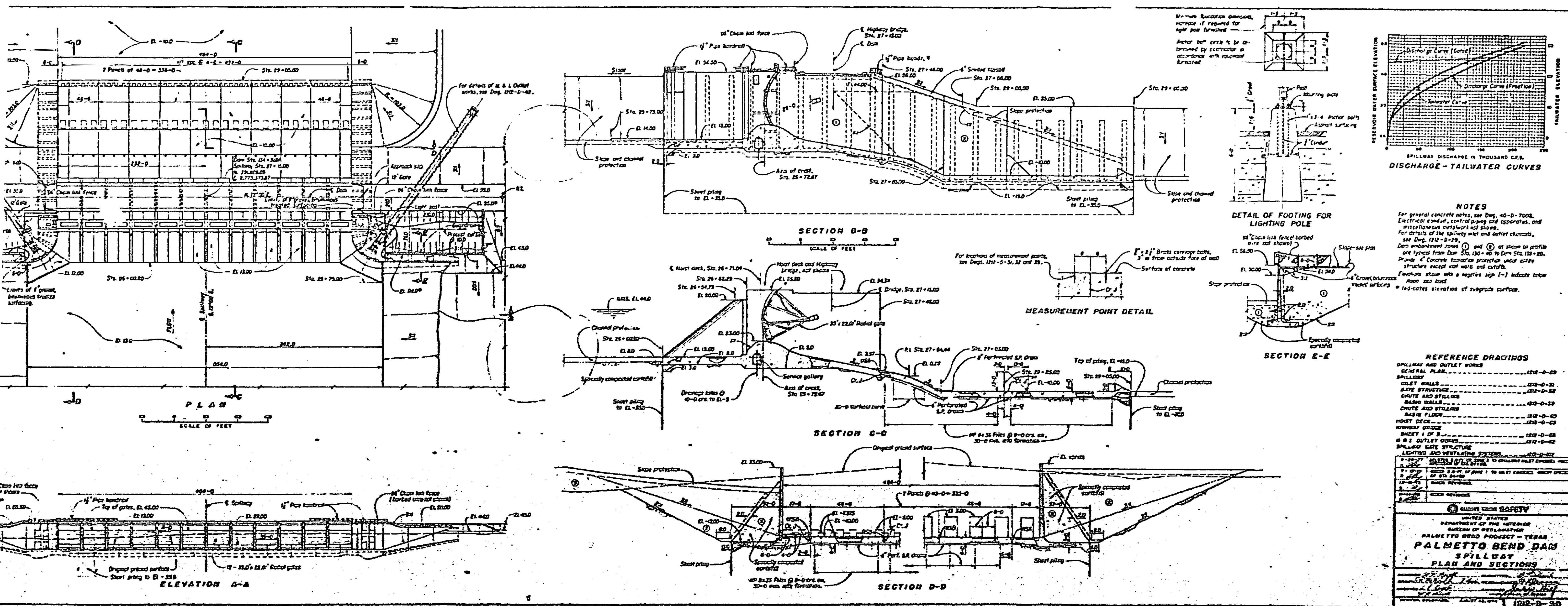

Figure 4. - Palmetto Bend Dam Spillway

GENERAL ASSESSMENT OF RISKS

Detailed case studies of the Bradbury, Norton, Blue Mesa, and Palmetto Bend Dams concluded that the logical choice to achieve project objectives under the given site specific conditions and economic constraints was to use gated spillways.

The primary concern of using gated spillways is the risk involved. For embankment dams with small reservoir storage capacity relative to the flood volume located above residential or commercial developments, the Service generally prefers the use of ungated spillways provided that site specific conditions permit. If gated spillways are needed for site specific reasons, it is the Service's policy that redundant or auxiliary devices be built in the design and operation of gated spillways.

Among the four case studies made in this report, Bradbury Dam is the only one with several residential and commercial developments along the river downstream from the dam. Bradbury Dam is also the one with small reservoir storage surcharge capacity (33,900 acre-ft) relative to the inflow design flood with a 3-day volume of 330,000 acre-ft. Consequently, special attentions were given to the design of Bradbury Dam on its evacuation capacity and the auxiliary or redundant devices to operate the gates. The gated spillways can evacuate 40 percent of the active reservoir capacity. The river outlet works and the Tecolate Tunnel have a combined capacity of 450 ft^3/s for reservoir evacuation. The gates are equipped with hydraulic automatic system with manual override. Electric power is supplied by commercial power with a backup engine generator. In addition to these redundant and safety features, 24-hour attendance is required when the spillway is in operation. Periodic inspection, tests, and improvements have been made on the Bradbury Dam to insure that gates are in excellent operational condition. The design, operation, and maintenance procedures used by the Service have significantly reduced the risks of using gated spillways for the Bradbury Dam. Similar procedures were used to reduce the risks for the Norton, Blue Mesa, and Palmetto Bend Dams. The risks involved in using gated spillways in these four cases are considered acceptable.

SUMMARY AND CONCLUSIONS

Selection of type of crest control for spillways is a complex matter. It requires a comprehensive understanding of factors which should be considered, advantages and disadvantages of using different types of spillways and gates, and current practice accepted by major agencies and firms with dam design and construction responsibilities. Information and analyses given in this report are general in nature. Case studies on four Service dams are used to illustrate certain types of crest control for spillways which were selected by the WPRS. Several conclusions can be drawn with respect to selection of type of crest control for spillways. The most significant of these conclusions follow:

1. A comprehensive analysis and evaluation of the geologic and topographic conditions, hydraulic and hydrologic factors, project objectives and flexibility requirements, hazard potential, operation and maintenance, and economics should be done before the selection on spillway type is made. The minimum requirement for a spillway is that it can be safely and economically constructed under the given geologic and topographic conditions to pass the inflow design flood. It should be emphasized that safety of the dam is a primary consideration that must not be compromised to reach other objectives.

2. Factors considered in the selection of the appropriate type of spillway should also be considered in the selection of the most suitable type of crest control and whether the crest should be gated or ungated. With respect to gated, special considerations should be given to the geometry of crest structure, hoisting equipment, potential operation problems, the need for backup systems, and the economic comparison of gated and ungated spillways in terms of the total cost.

3. Design simplicity, ease and flexibility of control, and operating reliability are important factors which should be considered in the design and selection of spillway gates and hoists. To increase the operating reliability, consideration should be given to backup power supply, hydraulic float operation, and automation.

4. Advantages of using ungated spillways include their ability to pass a given inflow design flood with a lower maximum rate of discharge and a lower rate of discharge increase than gated spillways, basically free from operation and maintenance problems, and higher degree of safety and reliability. The disadvantages include the requirements of higher surcharge elevation, larger storage volume and longer spillway crest to pass a given inflow design flood, the lack of ability to provide emergency evacuation from the critical upper reservoir level, the lack of flexibility in the reservoir operation (especially for multiobjective reservoirs), and the inability to accommodate a given inflow design flood without surcharge or without exceeding a restricted maximum allowable reservation water surface elevation.

5. Advantages of using gated spillways include their ability to pass a given peak discharge with lower surcharge elevation; smaller storage volume and shorter spillway crest length; the ability to provide rapid drawdown from the top of the gate to spillway crest for emergency evacuation, flexibility in reservoir operation, especially for hydropower, flood control, or other multiobjective reservoirs; and the flexibility afforded in maximizing the overall economic benefits of a multiobjective reservoir.

The disadvantages include higher rate of release and higher rate of discharge increase than ungated spillways for a given inflow design flood, the need for regular maintenance and constant attendance and regulation of control device, higher maintenance and replacement costs, the need for more hydrologic data in flood forecasting to ensure proper and effective gate operation, and higher hazard potential associated with improper maintenance and operation of a gated spillway.

6. Wherever a dam is built upstream from a population center and a short flood concentration time is combined with reservoir storage capacity that is small relative to the flood volume, ungated spillways are generally preferred if they are economically feasible. Wherever operational flexibility is combined with limitations on spillway crest length and

surcharge elevation, gated spillways are generally preferred. In cases where gated spillways may have some economic benefits over ungated spillways, the selection should not be at the expense of safety especially for an embankment dam constructed above a populated community.

7. Wherever gated spillways are used, they should be designed, insofar as practicable, so that peak rates of reservoir release during damaging floods do not exceed peak rates of the corresponding floods before the construction of the reservoir. In addition, the rates of increase in reservoir releases should be limited to values that would not constitute a major hazard to downstream interests.

8. A more cautious approach to crest control is needed for embankment dams than for concrete dams. Concrete dams can be overtopped in many instances without damage to the dam or its foundation. Such is rarely the case for embankment dams.

9. There are no standardized step-by-step procedures to follow in the selection of type of crest control for spillways. Careful, systematic, and comprehensive evaluation and assessment of all pertinent factors and the advantages and disadvantages of different feasible choices based on site specific factors and limitations should be done before the final selection is made.

RECOMMENDATIONS

The purpose of this report is to provide general information on selection of the types of spillway crest control that are suitable for site specific conditions, and to assess the various factors that are important to making such a selection. Particular attention is focused on gating of spillways for embankment dams weighing the advantages and disadvantages. The recommendations that follow are in keeping with the limited purpose of the report:

1. Guidelines for selection of spillway type and spillway crest control should be prepared for use by the Division of Design in order that a systematic and comprehensive evaluation and assessment will be uniformly applied to all spillways with appropriate consideration given to dam safety.

2. WPRS policy on means for controlling spillway releases should be flexible enough to accommodate the many site specific factors that should be weighed for each dam and reservoir.

APPENDIX A

References

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[2] Federal Coordinating Council for Science Engineering and Technology, June 1979, "Federal Guidelines for Dam Safety," Washington, D.C., p. 24

[3] U.S. Committee on Large Dams Committee on Failures and Accidents to Large Dams, Other than in Connection with the Foundations, 1970, "Criteria and Practices Utilized in Determining the Required Capacity of Spillways," p. 17

[4] U.S. Bureau of Reclamation, 1976, "Design of Gravity Dams," Chapter 9, Spillways, Denver, Colorado

[5] U.S. Army Corps of Engineers, 1959, Engineering Manual 1110-2-3600, "Reservoir Regulation," Washington, D.C., p. 12

[6] Harza Engineering Company, "Dams," Chicago, Illinois

APPENDIX B

Memorandum - Finding on Criteria for Automation of Spillway Gates

Form DPC-11
(12-61)
Bureau of Reclamation

INFORMATIONAL ROUTING

Appendix I

Memorandum
Chief, Division of Design

Denver, Colorado
June 24, 1971

Chief, Hydraulic Structures Branch
Attention: Mr. Fred Reed

Design Research Team for Automation of Spillway Gates

Finding on Criteria for Automation of Spillway Gates

Enclosed is the original of our report on Automation of Spillway Gates.

John G. Starbuck
Chairman

GPO 832-606

Enclosure

Approved by Hilf
7-22-71

Copy to: 220
G. H. Austin
E. A. Lindholm
J. G. Starbuck
L. M. Stinson
V. Smith
F. Reed

Automation of Spillway Gates

Introduction

Statement of Problem. - By memorandum dated April 14, 1971, concerning the subject "Criteria for Automation of Spillway Gates" the Chief, Division of Design, assigned this Design Research Team the following problem:

> Develop criteria for use by Bureau of Reclamation designers in determining the need for automatic controls for spillway gates on reservoirs impounded by earth and concrete storage dams with and without allocated flood control space, the selection of type of controls, limitations on rise in reservoir water surface to actuate the controls and the rise in reservoir water surface to fully open the gates, arriving at the maximum reservoir water surface elevation to be documented, and the guidelines for determining freeboard. Develop a means of evaluating the reliability of forecasting snowmelt runoff and rainfloods, the reliability of the power source, accessibility, cost, and other factors which may influence the omission of automatic controls.

The Design Research Team consisted of the following members:

Garry H. Austin	- Hydraulic Structures Branch
James Legas	- Hydraulic Structures Branch
Ernest A. Lindholm	- Hydraulic Structures Branch
John G. Starbuck	- Hydraulic Structures Branch - Manager
Lewis M. Stimson	- Hydraulic Structures Branch
Victor E. Smith	- Mechanical Branch

The problem as stated indicated the need for criteria for the use of automatic spillway gates where a gated spillway is required. As our study progressed, it became apparent that hard and fast rules for criteria could not be determined. The need for automatic controls must be studied on its own merits for each project.

The study of this problem was made during April, May, and June 1971. During this time the team held eight meetings 2 hours in length and discussed automatic spillway gates and controls with the following Bureau of Reclamation employees:

Paul L. Anna	- Electrical Branch
Merlin D. Copen	- Hydraulic Structures Branch
Donald A. Gray	- Water O&M
Peter E. Hanson	- Power O&M
Lyle M. Johnstone	- Power O&M
Fred D. Reed	- Hydraulic Structures Branch
Edward A. Serfozo	- Electrical Branch
Fred C. Walker	- Hydraulic Structures Branch

Literature Search

In an effort to obtain more information on the problem for Automation of Spillway Gates the Bureau library was researched for engineering references, but information directly related to the problem was not found. The information that was found was of such a general nature that it could not be used.

The research team reviewed the 1958 Abstract titled "Automatic Spillway Gate Control Questionnaire."

Correspondence

Correspondence was received from the Pacific Gas and Electric Company which elaborated on the use of local automatic control; this is discussed later.

Considerations Determining Use of Automatic Spillway Gates

A. Automatic Controls on Spillway Gates

1. Earth Dams. - Automatic Controls may be needed primarily for safety conditions to insure against overtopping and resulting failure. Actual need should be determined based on consideration of degree of attendance, reliability of communications, location of dam on the watershed, existence of upstream control features, custody of the structure and consequences of resulting damage or failure.

a. With allocated flood space. - Allocated flood space is normally established by the U.S. Corps of Engineers, both as to volume and method of release while the reservoir water surface is within this flood space. These controlled releases are used to lower the floodwater at some downstream location or to limit releases to safe channel capacity.

These controlled releases require operative attention whether local or remote. Since this control must be available until the flood pool is filled, it is assumed that similar control is available after the pool is filled. Automatic controls for the spillway gates might be eliminated in this case.

b. Without allocated flood space. - Releases become a matter of making certain that outflow does not exceed inflow, and control of the reservoir water surface and maintenance of freeboard become important. Automatic controls are of greater importance for this case.

2. Concrete Dams. - The need for automatic spillway gates on concrete dams is not the same problem as it is on earth dams. When concrete

dams are overtopped failure of the dam usually does not occur. However, the designers must consider damage or failure of appurtenances located at the toe of the structure. Automatic spillway gates usually are not required.

B. Types of Controls

Two general types of controls are available: hydraulic and electric. Electric control may be further divided into local and supervisory. Supervisory control is remote - manual.

1. Limitation of reservoir rise to actuate gates. - This depends on the individual situation. As a general guide a minimum of 2 feet of reservoir rise is usually required for reliable full cycle opening operation. This minimum interval will usually minimize the effects of wind upset. For the smaller gates it allows a reasonable ratio of gate opening to reservoir size for hydraulic systems and a reasonable arrangement of probe settings for electric automatic systems.

a. Water surface to actuate controls. - The actuating mechanism should be ready to operate when the reservoir water surface reaches the top of the conservation or flood control pool. However, a small rise in the water surface should be required to actuate the gates.

b. Water surface to fully open the gates. - This is an economic design problem involving the rate of reservoir rise, height of gates and the cost of dam height. The gates must not be too sensitive to small reservoir rises. They must be sensitive enough to rise when speed is required. A rate of 5-foot gate rise to 1-foot reservoir rise is common. Gates 50 feet high would require a reservoir rise of about 7 feet before the upper nappe would clear the gate bottom. This 7-foot added height of dam might be prohibitive in cost.

C. Freeboard Guidelines

1. Concrete Dams. - The crest of the dam is usually set at the maximum water surface, with a solid concrete upstream parapet providing protection against wave action.

2. Earth Dams. - Current general practice is to have 6 feet of freeboard on a surcharged reservoir or 8 feet of freeboard above the conservation pool without surcharge; these are satisfactory under normal circumstances. Freeboard criteria should also consider wind fetch. Under the safety of dams program it has been considered proper to reduce the freeboard for an existing dam to as little as 4 feet, providing the top of the dam is sound and to grade. The reduction in freeboard results from a reevaluation of

inflow design floods by the Hydrology Branch. This reduced freeboard should not be considered adequate for the design of new dams.

D. Evaluating and Reliability of Forecasting Runoff

1. Snowmelt. - Runoff from snowmelt can be forecast depending on the size of the watershed, number of observation stations and length of records with reasonable reliability as far as total volume is concerned. However, the intensity or concentration is subject to a wide range of variation because of possibility of unseasonably warm weather, rain, wind, and rain on snow.

2. Rainfall. - Forecasting is not reliable because cloudbursts and flash flooding may give insufficient time to take action, and damaging storms in remote areas may not be known.

E. Factors Influencing the Requirement for Automatic Controls and Types of Automatic Controls

1. Power source. - A reliable source of power is required for electric automatic controls. A dam with a powerplant is often considered to have a reliable source of power. Engine generators can supplement an unreliable source of power.

2. Attendance and accessibility. - If attendants are available, they will operate the gates and automatic controls are not required. If attendants are not available the spillway gates should have automatic or supervisory control. With the greater emphasis now being given to unattended dams, the use of automatic gates must be given thorough consideration especially if accessibility is poor.

3. Cost. - Not only the initial but the O&M costs must be considered when deciding whether to automate and what type of automation to use. Where the final features are unknown, it may be necessary to increase reconnaissance or feasibility estimates.

4. Others. - Reliable supervisory controls offer another alternative to the use of automatic controls. Methods of signal transmittal are:

a. Leased telephone lines.

b. UHF radio.

c. Cables.

d. Bureau-owned telephone lines.

e. The designer should know the advantages and disadvantages of each.

Automatic spillway gates usually will not be required on reservoirs [illegible]h allocated flood space or where major upstream storage structures [illegible]ovide controlled releases.

E. The decision to provide or omit automatic spillway gates on headwater storage structures should be based on the following considerations:

1. Rapidity of inflow and time available for operation
2. Attendance
3. Accessibility and communications
4. Custody of structures and degree of control and maintenance of automatic system
5. Consequences of overtopping
6. Reliability of forecasting

F. The type of control selected should be based on the degree of reliability required. Hydraulic controls are considered to be the most reliable. Some conditions for power supply might allow a close approach in reliability of electrical controls.

G. Usually automatic spillway gates are not required on concrete dams.

H. Water O&M should update and disseminate the data contained in the 1958 survey "Automatic Spillway Gate Control Questionnaire."

Criteria of Other Agencies

1. Government. - The Bureau of Reclamation apparently is the only Government agency that is a major user of automatic spillway gate controls. This is the result of building major storage structures near the headwaters of drainage systems, allowing economics to control the choice of gated versus free overflow structures and a policy of reducing operational staffing to a minimum.

2. Private. - PG&E uses automatic spillway gates for local automatic control that respond at preset reservoir levels and are sequential in operation. They are also used in backup for the supervisory in the event of control or microwave failures. PG&E reports that vandalism has become critical in their automatic systems operation.

G. Considerations for Design and Operation

1. Planning. - Definite determination relative to project operation should be made in the planning stage and be included in the design data as to the staffing and project operation. This should be in the earliest planning stage practicable and a definite commitment made no later than in specifications design data. Incoming design data should be reviewed by Regional Director's staff for statements regarding the adequacy and the proposed method of operation. Data should be projected into the future to determine whether the method of operation will remain stable.

2. Operating hydrology. - Hydrologists must give and perform the best forecasting techniques relative to flood and reservoir operation.

3. Operation and maintenance. - Instructions on operation and maintenance of automatic gates should be stated in such a way that they are readily understood. The competency of the operating and maintenance personnel should be subject to review.

Recommendations and Conclusions

A. No arbitrary rule can be made to omit or include automatic spillway gates. The designers, in cooperation with the Project, Region, and O&M forces, should be given the task of deciding the solution for each structure.

B. Definite determination relative to project operation should be made in the planning stage and be included in the design data. This should be made in the earliest planning stage and a definite commitment made in the specifications design data.

C. Automatic spillway gate controls generally will not be required for earth dams where a powerplant or project operating headquarters provide a 24-hour watch or another high degree of attendance.

Automatic spillway gates usually will not be required on reservoirs with allocated flood space or where major upstream storage structures provide controlled releases.

E. The decision to provide or omit automatic spillway gates on headwater storage structures should be based on the following considerations:

1. Rapidity of inflow and time available for operation
2. Attendance
3. Accessibility and communications
4. Custody of structures and degree of control and maintenance of automatic system
5. Consequences of overtopping
6. Reliability of forecasting

F. The type of control selected should be based on the degree of reliability required. Hydraulic controls are considered to be the most reliable. Some conditions for power supply might allow a close approach in reliability of electrical controls.

G. Usually automatic spillway gates are not required on concrete dams.

H. Water O&M should update and disseminate the data contained in the 1958 survey "Automatic Spillway Gate Control Questionnaire."

APPENDIX C

Memorandum - Proposed Alternations to the
Control System at Bradbury (Cachuma) Dam,
Cachuma Project

Form DFC-11
(1-54)
Bureau of Reclamation

INFORMATIONAL ROUTING

Memorandum

Denver, Colorado
January 8, 1959

Chief Designing Engineer

Chief, Mechanical Branch

Proposed alterations to the control system for the four 50- by 30-foot automatic float-operated spillway radial gates at Cachuma Dam--Cachuma Project

AUTHOR

GPO 845867

Purpose of This Memorandum

As a result of the memorandum for Files by T. A. Polley dated June 3, 1958 (reference 2 below), the task of analyzing the subject control system was assigned to R. W. Fowler of this branch. Some dangerous features were discovered, and corrective measures are recommended.

References

1. Memorandum of May 13, 1953, "Testing of Spillway Gates--Cachuma Dam," from Field Engineer, Cachuma Branch to Chief, Construction Division.

2. Memorandum for Files dated June 3, 1958, by T. A. Polley, Region 2.

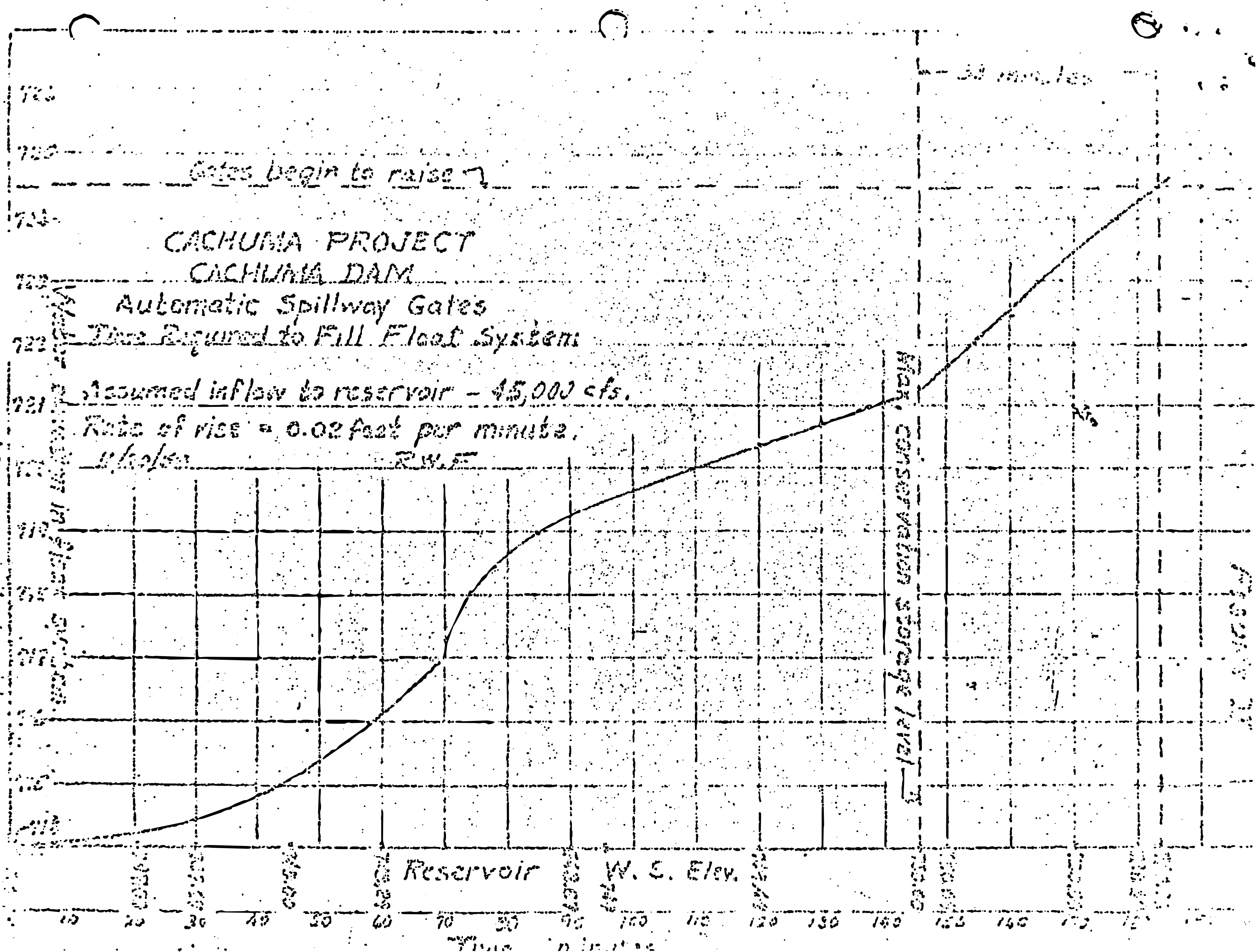
3. Letter of November 13, 1958, from Assistant Commissioner to Regional Director, containing instructions for operation through the 1958-59 flood season.

4. Report by the Area Engineer, Durango, Colorado, regarding operation of Vallecito Reservoir, July 24 through July 27, 1957, with transmittal letter dated August 15, 1957.

5. "Abstract of Automatic Spillway Gate Control Questionnaires," prepared by Irrigation Operations Division (Table I).

The Dam and Flood Routing Considerations

Cachuma Dam is located in Santa Barbara County, California, on the Santa Ynez River. It was completed in 1953, under Specifications No. 3684. It is an earthfill structure 276 feet high, having a concrete spillway of 161,000 cfs capacity. The two 30-inch river outlet valves have a combined capacity of about 750 cfs at maximum head, and are of negligible consequence in flood routing. The spillway invert is at elevation 720. The


CACHUMA PROJECT
CACHUMA DAM
Automatic Spillway Gates
Time Required to Fill Float System
Assumed inflow to reservoir - 45,000 cfs.
Rate of rise = 0.02 feet per minute.
Gates begin to raise
Reservoir W. S. Elev.
Time in minutes
RWE

Form DFC-11
(7-52)
Bureau of Reclamation

INFORMATIONAL ROUTING

Appendix III

Memorandum

Chief Designing Engineer

Denver, Colorado
January 8, 1959

Chief, Mechanical Branch

Proposed alterations to the control system for the four 50- by 30-foot automatic float-operated spillway radial gates at Cachuma Dam--Cachuma Project

AUTHOR

GPO 84586

Purpose of This Memorandum

As a result of the memorandum for Files by T. A. Polley dated June 3, 1958 (reference 2 below), the task of analyzing the subject control system was assigned to R. W. Fowler of this branch. Some dangerous features were discovered, and corrective measures are recommended.

References

1. Memorandum of May 13, 1953, "Testing of Spillway Gates--Cachuma Dam," from Field Engineer, Cachuma Branch to Chief, Construction Division.

2. Memorandum for Files dated June 3, 1958, by T. A. Polley, Region 2.

3. Letter of November 13, 1958, from Assistant Commissioner to Regional Director, containing instructions for operation through the 1958-59 flood season.

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5. "Abstract of Automatic Spillway Gate Control Questionnaires," prepared by Irrigation Operations Division (Table I).

The Dam and Flood Routing Considerations

Cachuma Dam is located in Santa Barbara County, California, on the Santa Ynez River. It was completed in 1953, under Specifications No. 3034. It is an earthfill structure 276 feet high, having a concrete spillway of 161,000 cfs capacity. The two 30-inch river outlet valves have a combined capacity of about 750 cfs at maximum head, and are of negligible consequence in flood routing. The spillway invert is at elevation 720. The top of the spillway gates and the top of the conservation pool are at elevation 750. Maximum conservation storage at elevation 750 is 210,000 acre-feet, and reservoir surface area at that elevation is a little more than 3,000 acres. The design flood, Drawing No. 353-D-593, is 183,000-cfs peak; and the maximum historic flood, March 1938, was 43,700-cfs peak. Annual runoff has been very erratic, varying from zero in 1948, to 478,000 A.F. in 1941. Drainage area is 421 square miles. There are several small towns in the Santa Ynez Valley downstream from the dam; and the river is crossed by the Southern Pacific Railroad, U. S. Highway 101, and other lesser highways.

Design of the automatic spillway gates

Figure I, a freehand schematic of the control system is included in this memorandum as an aid to understanding the design and operation of the gates. The design is described as it was originally installed, and as it was during the spilling period of April 1958, as reported by Mr. Polley (2). (The Assistant Commissioner's letter of November 13, 1958, (3) ordered that control inlet weirs be lowered and that the overriding feature of the hoist clutch be eliminated for operation through the 1958-59 flood season. These are the only features that now differ from the description which follows):

There are four 50- by 30-foot radial gates having cantilever mounted counterweights. The gates are hoisted in the usual way by wire ropes attached to the upstream skin plates.

A 3-horsepower, 2 foot per minute electric hoist is provided for each gate to supplement the normal float operation, driving through an overrunning clutch so that float operation will always take over to raise the gate if the reservoir rises above a predetermined level. A 7-1/2-kilowatt generator, powered by a gasoline engine, is provided for standby electric power supply to the hoist motors.

Two floats are connected by wire ropes to the hoist of each gate, one at each side, weighing a total of 37,000 pounds and having a combined buoyancy of 4,100 pounds per foot of submergence. Each float is 9 feet 1 inch high.

Two concrete counterweights are attached by wire ropes to the hoist of each gate to assist the electric hoist or the floats in raising the gate. Total weight of the two counterweights is 48,000 pounds.

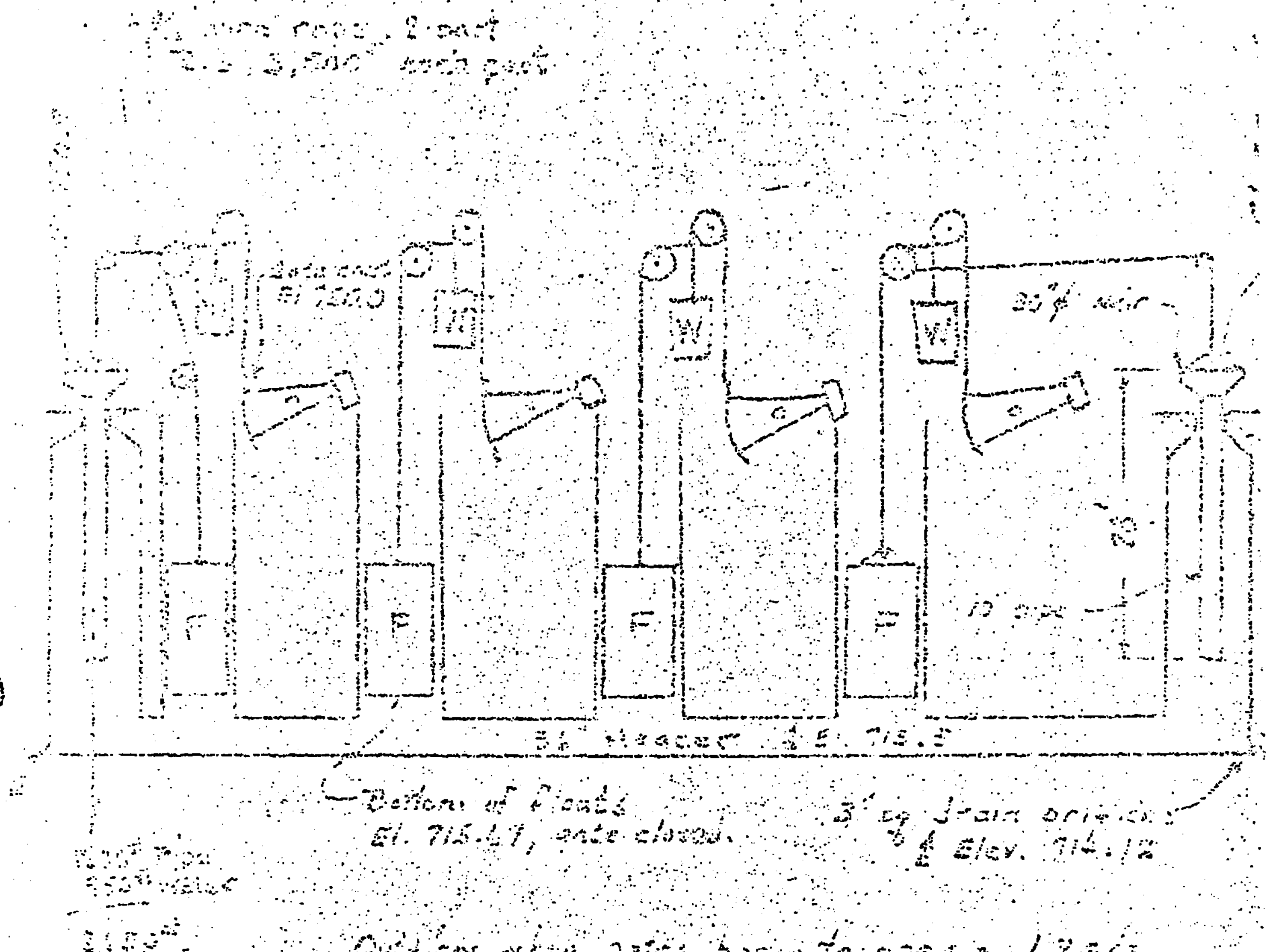
The float wells of all four gates are interconnected by a 36-inch header so that, friction and operating forces being the same, the gates would theoretically operate in unison. Water is admitted to the float system when the reservoir overflows either of two 30-inch diameter weirs located in the abutments adjacent to the spillway, and flows out of the system through two 3-inch square

Cachuma

Cachuma Dam

Original Control Scheme

Fig. 1



Outflow when gates begin to open = 1.9 cfs

Height of reservoir, one weir = 0.18' over weir

Height of reservoir, two weirs = 0.11' over weirs

Volume of float system to begin operation 2000 cu metering orifices located in the very bottom of the system. If inflow over the controlling weirs exceeds outflow from the orifices, water will rise in the floatwells and the gates will move in the opening direction. Conversely, if inflow is less than outflow, the gates will move in the closing direction. The right inlet weir is attached to the hoist of the right gate, and the left inlet weir to the hoist of the left gate, by 3/16-inch wire ropes. When the right or left gate is raised, the corresponding weir is raised also - about 1/4 as much as the gate, thus decreasing the inflow of water and arresting upward motion of the gates. Since the weir movement is 1/4 that of the gates, an increase of 8 feet in reservoir level is required to raise the gates the full 30 feet. Original instructions called for the right inlet weir to be set at elevation 750.32 and the left inlet weir at elevation 750.9; and for the main cantilever counterweights to be adjusted so the dry gates would begin to rise with floats about half submerged. This was done in May 1953. (Ref. (1).)

Summary of Field Test Data

Following is a brief and simplified summary of the May 13, 1953 field test report and of Mr. Polley's report of the tests of April 8 and 15-16, 1958. For the purpose of simplification, only Gate No. 1 data will be followed, the information in Mr. Polley's report being more complete on that gate:

1. In the dry tests of May 1953, the float submergence to begin raising the gates was about 4-1/2 feet. No. 1 gate required the most float submergence at 4.91 feet.

2. April 8, 1958, with 24.8 feet of water standing against the gates, the required float submergence to begin hoisting was about 3 feet more than for the dry gates. It was 7.93 feet for No. 1 gate. Thus, the required rope pull was 12,400 pounds greater than for the dry gate.

3. By April 13, the reservoir had risen to elevation 750.6, overtopping the gates 0.6 foot, and the floats failed to raise any of the four gates. All floats were completely submerged.

4. April 16, 1958. Hoist counterweight of Gate No. 1 was increased 5,500 pounds. Then, with 0.6 foot of water overtopping the gate, float submergence to begin hoisting was 8.64 feet; or, the rope pull was 20,800 pounds greater than for the dry gate.

5. While on float control the gates hunted continually, about 0.4 foot, which produced a ragged flow chart on the downstream recorder, and made it difficult to compute water releases.

Mr. Polley's recommendations for correcting the float operation are as follows:

1. Eliminate overflow of the gates by lowering the control weirs or by adding 6 or 8 inches to the top of each gate.

2. Add 3 feet to the depth of each float, and about 4,000 pounds to each hoist counterweight.

3. Replace the 3/16-wire-rope now supporting the weirs with 5/16-wire-rope to reduce rope stretch, permit the weirs to more accurately follow the movement of the floats, and thereby reduce hunting of the gates.

Discussion of Field Test Data

Forces contributing to the 20,800-pound increase in hoisting effort as the water rises up the gate and overflows the top 0.6 foot deep are:

A. Hydraulic load on top of the gate
B. Hydraulic load on back of gate due to curvature
C. Increase of bearing and seal friction
D. Hydraulic load on bottom gate seal
E. Unknown hydraulic loading due to possible irregulatiries in shape of upstream skin plate

Item A is simply the area of the top plate multiplied by the water depth and density; or 2,800 pounds.

Item B is approximately 1,200 pounds.

Item C increases as the square of water depth and would be expected to be about 2,000 pounds.

Item D is the area of the seal projection times h; or 5,800 pounds.

$$A + B + C + D = 11,800 \text{ pounds}$$

$$\text{Item } E = 20,800 - 11,800 = 9,000 \text{ pounds}$$

In the case of the test of April 8,

$$A = 0,\ B = 0,\ C = 1,300,\ D = 4,900$$

$$E = 12,400 - 6,200 \text{ pounds} = 6,200 \text{ pounds}$$

Whatever the unexplained Force E comprises, it increases approximately as the square of the head against the gate.

The projecting bottom and side seals introduce excessive friction and variable hydraulic loading, requiring greater float capacity andhandi-capping automatic operation; but nothing can be done about this at Cachuma while the reservoir remains up on the gates, which may be for several years. The cause of the unexplained hydraulic loading is likewise inaccessible. Since the primary causes of the increased loading are not accessible at present, it will be necessary to provide about 3 feet of additional float depth to absorb the variable load, as recommended by Mr. Polley.

The reservoir should not be permitted to overtop a float-operated gate. Control weirs should be set low enough, or the gates should be high enough to preclude overtopping. In the case of Cachuma, with maximum irrigation storage level established at elevation 750.0, and about 9 feet of surcharge permitted, the best course will be to add a 1-foot splashplate to the top of each gate. Control weirs should be set to close the gates as the reservoir subsides to elevation 750.0, which will necessitate the gates beginning to open when the reservoir rises 2 or 3 tenths of a foot above elevation 750.0 since friction requires some differential between opening and closing. Control weirs should be a tenth or so above minimum control level so winds piling water against the dam will not cause false gate operation.

Hunting is objectionable from the standpoint of water recording, as mentioned by Mr. Polley. It also causes wear of gate and hoist parts and gives visitors an impression of poor control. It should be eliminated if possible. The Division of Irrigation Operations sent out questionnaires early in 1958, to all projects having automatically-controlled spillway gates. The replies have recently been abstracted, (Table I) and hunting of the gates is by far the most prevalent complaint. However, the possible consequences of hunting are actually less serious than the possible consequences of some of the measures taken to overcome it.

The hunting of the Cachuma gates is not due to stretching of the weir cables. Cable stretch would reduce the movement of the weirs and tend to reduce hunting. Hunting of the Cachuma gates is due to the inherent characteristics of the moving weir control system. A means of overcoming the hunting action is proposed herein. Undoubtedly, as Mr. Polley stated, the overtopping of the gates would contribute to hunting due to its own variation with the hunting.

There are other seriously dangerous features of the existing design which should be considered and corrected:

The use of only two control weirs connected to Gates 1 and 4, but serving the float wells of all four gates through a common header, introduces a very definite hazard. Double the historic flood could be released with reservoir water level only 750.6. If Gate No. 1 were to stick closed so that the right control weir would not be raised with the rising reservoir, the other three gates would begin opening at water surface 750.5 and would be wide open at 750.6,

ABSTRACT OF AUTOMATIC SPILLWAY GATE CONTROL QUESTIONNAIRES

	Project	Dam	(1) No. of gates	(2) Size Ft. wide	(2) Size Ft. high	(3) How many of gates are on auto. control?	(4) Gates are actuated Elect.	(4) Gates are actuated Mech.	(5) Are auto. controls now in good condition?	(6) How did control become inoperable, if they are?	(7) Please suggest any improvements in design to improve operation or maintenance.	(8) Do you consider automatic control of spillway gates to be desirable? Why?	(9) What do you think of automatic spillway gate control as a safety device?	(10) What has been your method of operation when reservoir is full or nearly so?
1	Boise	Anderson Ranch	2	25	22	Both	X		Yes but not used			No. On this project river flows must be maintained at as near a constant rate as possible. Automatic controls have a tendency to hunt and make small changes. We prefer to make larger changes spaced farther apart and to have exact knowledge of all changes and time of change. Normally flows are regulated by flood control forecasts.	They are not necessary where powerplant superintendent and operators are in close attendance and flows are regulated by flood forecasts.	Reservoir elevation is watched closely and discharge is maintained at amounts set by observation of inflow and forecasts for flood control.
	Burnt River	Unity	2	25	16	Both		X	No	Combination of both	Modern design with electrical actuation and controls.	No. River flows downstream normally have to be carefully regulated and it is necessary that the caretaker be aware of all changes. Wind pileup can cause gate changes and inherent characteristics result in hunting and movement of gates when not required. Discharge is normally controlled by flood forecasts.	Do not believe they are necessary where dam is attended at all times or is closely observed.	Discharges are controlled by observance of inflow and flood forecasts.
	Boise	Cascade	2	21	20	Both	X		No but could be reconditioned without too much work.	Controls are not used and are not maintained		No. Automatic controls are sensitive to inconsequential changes in reservoir water surface elevations caused by water pile-up and waves from wind action. These changes in water surface elevations cause unnecessary and erratic movement of the gates resulting in sudden and substantial fluctuations in downstream discharges. Such changes coming without warning cause distress and damage along the river. It is preferable that changes in river flow be deliberate, gradual and in accordance with plans.	Not too important a factor where dam is closely attended and observed during the critical filling period.	Regulation is in accordance with inflow forecasts and flood control plans.
	Umatilla	McKay	6	20	10	2	X		Probably are ok. One is out.	One was changed to provide an alarm circuit at the house.	Two siphon spillways are built into the dam spillway structure which affords additional emergency capacity.	No. I have not used them so have no experience to comment on.	I do not believe that they should be depended upon. It seems that if the situation is critical enough for the automatic gates to take over, the person in charge should be on hand. Human failure is no more likely than power failure in such cases. Fluctuating flows, I believe, cause more damage downstream than a steady flow.	Taking into consideration the condition of the watershed, weather conditions, forecasts, and the water elevation in the reservoir, I try to adjust the outflow with the inflow in order to take the crest off any sudden rise in inflow and still not use up reservoir space too fast, or cause too much damage downstream. There is always the possibility that a crest can be handled, using up space, and then not another upsurge in the inflow and no place to put it. The only thing to be done then is to pass it on through. When the reservoir is nearly full, I keep a close check on the inflow both day and night.
	Boise	Black Canyon	1 (drum)	64	16	3			Probably but are not used.			No. Automatic control for drum gates would work if the wind never blew. On a landlocked lake the wind causes waves to be formed and a drum gate on automatic control will follow these waves. Movement of the drum gate amplifies the waves and in a short time the drum gates make periodic movements which increase as the waves are amplified. I have watched the drum gates at Black Canyon Dam when they were placed on automatic control. In less than 2 hours after the wind commenced to blow the gates would drop as much as 1 foot and then rise to the set elevation in the matter of a very few minutes. The longer the gates were on automatic control the more violent the movement of the gates.		Manual control of gates is used.
	Vale	Agency Valley	3	15	17	3	X		No	Feed pipe plugged. Float apparatus out of order.		Officials of the Vale Irrigation District feel there is no need for automatic operation of the spillway gates inasmuch as the Reservoir Superintendent's house is only a few hundred yards from the gates. The gates "hunted" when first placed on automatic operation and, consequently, the use of the automatic controls was discontinued. The float well feed line has since become plugged and the float apparatus is out of order.		When the reservoir level is approaching the top of the gates the Superintendent does not leave the immediate vicinity. The gates are controlled manually.

5a

TABLE I

			(1)	(2)		(3)	(4)		(5)	(6)	(7)	(8)	(9)	(10)
2	Cachuma	Cachuma	4	50	30	All 4		X	Not all	Inadequate counter-weights	The gates can probably be made to operate OK by addition of struts. Floats should have been designed larger for greater margin of safety.	Not generally. These gates failed to open automatically when first tried. One gate was made to operate automatically by adding 1,500 lbs. to its counterweight.	The benefits appear to be outweighed by the possibilities of malfunction and the higher first cost.	Gates initially had to be raised by electric motors (manual control). Automatic operation is expected to be used, after modification, on either one of all four gates.
3	Palo Verde	Palo Verde Diversion	3	50	25	All 3	X		Yes		System has operated only 6 months. No problems have been disclosed.	The forebay water surface must be held constant and to date the automatic controls have worked very well. While a gate tender is on the job around the clock, the automatic control gives him considerable freedom to pursue other duties.	No comment	No comment
	Boulder Canyon	Imperial	12 3	14 35'-8"	7 16'-6"	All originally	X		No	Dismantled	Install roller bearings or bearings with less friction and provide for close adjustment of gate seals.	It all depends upon operating requirements. The need for constant attention to and close regulation of the Colorado River at Imperial Dam precludes the use of automatic controls. The storage space above the dam, some 1,500 acre-feet, is utilized to conserve the flows and avoid unnecessary waste. This entails operating the lake at various levels from day to day. The level of the lake is also varied to maintain diversions when the trash load is very heavy.	Under some conditions they are necessary	The sluiceway gates at Imperial Dam which are used to regulate the operating level of the lake are manually operated. This type of operation gives us better control. The automatic control device of the 3 Gila headgates is for the purpose of maintaining a constant elevation in the desilting basin when water is spilling over the top of the weir crest. Since the lake elevation is kept below the weir crest there is no requirement for this automatic control. The 12 California sluiceway gates were equipped with automatic controls for each 4 gates but testing, and the need for even distribution of the flow to prevent erosion, made it necessary to discontinue the use of the automatic controls.

Information concerning the automatic gates at the Siphon Drop Power Plant forebay was supplied by the Yuma Project. These gates are well maintained so that they are always ready to waste water rejected by the power plant. They are quite satisfactory.

The Gila Project submitted information regarding the several automatic wasteway gates on the Gila Main Canal and on the Wellton-Mohawk Division. Most of these gates are for the purpose of protecting the canal from sudden inflows of storm water. They are checked frequently at regular intervals to insure that they are constantly in readiness to operate.

The Imperial Irrigation District supplied information on the automatic gates on the All American Canal including those at the Pilot Knob Spillway which are designed to waste water rejected by the district's power plant. Drops 1, 2, 3, 4, and 5 have been provided with automatic gates to provide safety in canal and power operations. All of these gates are being used except No. 1 which has been dismantled since it was not needed now. The Imperial Irrigation District has reworked several of the automatic gate mechanisms, to improve their operation, by installing larger rope drums and frictionless bearings. The automatic gates are serving very well.

The Coachella Valley County Water District furnished data on the automatic gates on the Coachella Canal which serve to protect the canal against damage from storm water entering the canal and from other high water conditions. As in the case of the three preceeding reports, automatic gates here are kept maintained in operable condition and they are depended upon to afford the protection they were designed for.

	Salt River	Horseshoe	3	114	26	All 3		X	Yes		No comment	Yes. When 24-hour continuous operating shifts are not maintained, automatic gates can reduce flood damage.	They are very desirable.	Ordinarily the gates are operated as the reservoir is filling to minimize flood discharges and to correlate with the downstream reservoir.

The Salt River Project also reported that an automatic spillway gate on the Grand Canal had been taken out of operation by dismantling because the float chamber had a tendency to silt up and it could not be depended upon to protect the canal from flood waters.

4	Weber River	Echo	4	18	17	All 4	X		Yes, excellent		The operation of the automatic controls was entirely unsatisfactory as originally installed. The gates constantly raised and lowered even from wind action on the reservoir. In 1955, the 3" inlet pipe was replaced with a 1/4" pipe to the float wells. The automatic controls now hold the reservoir elevation almost constant even with fluctuating inflow.	Yes. It would be practically impossible to maintain as good control of the reservoir storage by manual control as has been possible by automatic control, after improvement of inlet piping.	Excellent	The automatic control has not been switched into operation until the reservoir approaches spill level. The controls are disconnected after storage drops below spill level.

		(1)	(2)		(3)	(4)		(5)	(6)	(7)	(8)	(9)	(10)
Moon Lake	Moon Lake	2	26	17.5	Both		X	Yes		Gates rise too much when opening and close too much when closing making the outflow more erratic than the inflow, or high and low inflows are exaggerated.	Yes. Automatic operation provides a safety factor. Often the capacity elevation is reached at night and an all-night watch is unnecessary with automatic controls. Also, the tendency of people to want to use their own judgment as to safe elevation, etc., for storage is largely overcome by the automatic controls.	Our experience is that they are a safety device.	As a rule we use the gas motors to lift the gates and release a reasonable flow but allow the automatic controls to operate if we have under-estimated the flow necessary to balance the inflow.
Boysen	Boysen	1	14	7.5	1		X	Think so, gate has not operated for 6 years.		Have not operated the gate enough to determine and no procedure has been formulated to test the performance in advance of a potential flood.	Depends upon circumstances. Because of low water the spillway has not been required to operate for the past 6 seasons. Also there is an emergency spillway which has been used in the past. For these reasons there is some question whether or not an automatic spillway gate is the proper installation in this case.	There is always the question of dependability of these gates, because of their somewhat intricate design, which detracts from their use as a safety device.	The gate was used once, in 1952, since its installation in 1949. Before it would work automatically as intended, some alterations were necessary to its original design, mainly to the weir plate and the outlet pipe from the float wells.
Pine River	Vallecito	3	37	19	All 3		X	Were OK in July 1957. Not tested yet this year.	Controls are operable.	Cannot suggest any improvements.	No. We do not believe that automatic control of spillway gates at Vallecito is necessary because during the period the reservoir is full or nearly so the Reservoir Supt. is in constant attendance. With a positive mechanical control of the gates releases can be more accurately regulated.	Not necessary where there is adequate attendance.	The only time it has been necessary to operate the spillway gates to regulate excessive inflow to the reservoir was on July 26 and 27, 1957. For details of this operation see report attached to letter of August 15, 1957, from Regional Director, Salt Lake City to Assistant Commissioner and Chief Engineer, Denver. Subject, "Operation of Automatic Control of Spillway Gates, Vallecito Dam--Pine River Project, Colorado."
Truckee Storage	Boca	2	19	16	Both	X		Yes		Be sure that adequate protection or housing from the weather is provided at the time of installation.	Yes. Excellent for maintaining level of the lake. Would suggest that the controls be designed to operate over a greater range in elevations. Controls now operate over only the top 2 to 4 feet of reservoir storage. Simplify electric system to reduce number of contacts.	Not too good as a positive safety device. Dependability somewhat questionable. Probably adequate protection will or has remedied this situation.	Automatic controls used when reservoir is full by setting limit switches to prevent full gate opening in case of short circuit. Mainly control to operate the gates more frequently but in smaller degrees of opening in effecting changes in discharge.
5 Carlsbad	Alamogordo	3	45	21	All 3		X	Yes		The float operating mechanisms have not been a maintenance problem. Some adjustment should be provided to permit the reservoir elevation to be held at varying levels, within limits. This would simplify planned operations.	Yes, as a safety device. In addition to the automatic controls the gates may be raised by gasoline powered hoists and by a crank on the hoists. By gasoline power all gates may be opened in about an hour. By hand crank it would take 10-1/2 hours per gate. Without the automatic float control there could be serious trouble in time of flood if the gasoline power failed. This is less serious since the building of the emergency spillway than it was before.	The automatic controls are safety devices when there is no control of stream flow above the dam and no flood warning is available, also, in case emergency operation is necessary and there is failure of the mechanical means of operation. With only one employee stationed at the dam, the automatic controls are very desirable in times of emergency.	The gates operated automatically to pass three major floods in 1941 and 1942. On the receding stages of these floods, the gates were operated manually rather than by the float controls. In general, the gates are operated mechanically whenever possible as steadier flows can be maintained. Peak flows can frequently be reduced somewhat by planned operation.
Rio Grande	Caballo	2	50	22	Both		X	Yes		Each gate should operate independently.	Automatic control has never been experienced at Caballo. If conditions of storage should develop that might result in automatic opening of the spillway gates we would close the valve to the inlet in order to prevent opening as river conditions below the dam must be considered. Storing of a flood peak for a few hours above elevation for automatic opening might prevent serious flood damage in valleys below the dam.	If a damtender is stationed at the dam and double communications system, telephone and radio, and open highway are available; don't think the automatic controls are necessary for safety.	Have used auxiliary pumping to float wells, in 1942. Don't like Caballo set-up of both float wells being controlled from same inlet source.
6 Riverton	Bull Lake	3	29	11	All 3		X	Yes		It was necessary to install baffle plates to prevent the splashing of waves into the float wells.	Yes, in spite of malfunctioning when they first operated. The first time the reservoir level was allowed to get near normal maximum, strong winds caused waves to break over the tops of the piers and into the float wells opening the gates and releasing a big head of water. Baffle plates were installed to prevent this. See letter of Oct. 4, 1951, to Chief Engineer from Riverton Project Manager, subject, "Spillway gates--Bull Lake Dam."	They are all right if kept in good operating condition.	We do not use the automatic controls to control the surface elevation of the reservoir due to danger of opening wide during storms.
7 Missouri River Basin	Enders	6	50	30	All 6	X		Yes		No comment.	Yes. A single operator is in attendance. In the event of illness or accident, dam might be unattended temporarily.	They are often an economical design alternative for long overflow sections.	No experience to date.
Missouri River Basin	Trenton	3	42	10	All 3		X	Yes		No comment.	Yes. A single operator is in attendance. In the event of illness or accident, dam might be unattended temporarily.	They are often an economical design alternative for long overflow sections.	No experience to date.
Missouri River Basin	Lovewell	2	25	20	Both		X	Yes		Free suspension of the adjustable weirs on 1/4-inch cable has proven unsatisfactory. We are presently replacing the single 1/4-inch cable with steel rod links and are providing guides to prevent rotation of the weir. This should eliminate difficulties arising from torsional stresses in the cables.	Yes. A single operator is in attendance. In the event of illness or accident, dam might be unattended temporarily.	They are often an economical design alternative for long overflow sections.	No experience to date.

		(1)	(2)		(3)	(4)		(5)	(6)	(7)	(8)	(9)	(10)
Missouri River Basin	Webster	3	33.33	30.51	All 3		X	Yes		Free suspension of the adjustable weirs on 1/4-inch cable has proven unsatisfactory. We have replaced the original plow steel ropes with non-rotating ropes. If this is not adequate we will provide guides to prevent rotation of the weirs	Yes. A single operator is in attendance. In the event of illness or accident, dam might be unattended temporarily.	They are often an economical design alternative for long overflow sections.	No experience to date.
Kendrick	Alcova	3	40	25.67	All 3	X		Yes		The automatic controls have never been used because they are not needed at this dam.	No. Operating conditions at Alcova do not permit the use of automatic controls. See letter of April 22, 1959, to Regional Director, Denver, from Acting Project Manager. Subject, " Information on automatic spillway gate controls."	Not desirable for this application.	Content of Alcova reservoir depends upon releases from Pathfinder Dam and from Alcova. River flow in the Casper area must be limited to about 7,000 cfs. to prevent damage. Irrigation demands require up to 5,300 cfs. so a relatively small error in automatic controls on the spillway could release damaging floods down the river. All of our gate controls can be operated only while the operator is holding and watching the controls.
Colorado-Big Thompson	Shadow Mountain	2	18	20	Both	X		Yes		We have added a positive power interlock to these gates to prevent possible floods below Shadow Mountain as a control economiztor or if supervisory equipment functioned improperly. I recommend that any automatically-controlled gate have such an interlock or a mechanical interlock which can be adjusted to prevent unduly wide opening and dangerous flooding during times when large gate openings would not be required for normal operation.	Yes. These gate controls have been used very little to date because the control could be shifted from automatic to manual from the Granby Pumping Plant and manual operation was preferred in the past. The gates were placed in automatic operation this spring and under certain inflow conditions, relieve the operators of the necessity of constantly adjusting flows. There are other conditions where automatic operation of the gates is not desirable as it is necessary to maintain sufficient head difference between Grand Lake and Shadow Mountain Lake to permit the inflow to pass through.	Automatic controls provide some safety against over-topping the dam or suddenly changing releases due to poor manual operation. However, safety functions are off-set by the possibility of faulty automatic operations causing the same type of thing that they may prevent from operating errors.	Not applicable. Reservoir is maintained within one foot of elevation at all times.
Colorado-Big Thompson	Granby	2	21	20	Both	X		No	Neither	The automatic controls are not operable because the intake pipe to the float well is broken and it has been capped to prevent saturation of the dam.	No. The float controls on Granby gates have never been used as the reservoir has never reached its maximum capacity. Due to the large area of Granby Reservoir I do not think it will ever be necessary to use the float controls for the protection of the dam and dikes and if the reservoir does reach its maximum, very close regulation will be made to keep the spill to a minimum to avoid damage to the spillway and the streambed below. I do not believe automatic operation should be depended upon where operators are reasonably available for manual control of the gates and where inadvertent excess openings would result in major floods.	I do not recommend them at or adjacent to attended installations.	

releasing 87,000 cfs. If Gate No. 4 were to stick closed, the other three gates would begin opening slowly at w.s. elevation 750.5, then would rapidly open all the way between w.s. 751.1 and 751.2.

If either of the 3/16-inch wire ropes which suspend the two weirs were to break, all four gates would go wide open if the water surface at the time were 750.6 or higher in the case of the right weir, or 751.2 in the case of the left weir.

These are not remote possibilities; but even if they were remote, the risk would be too great to justify.

The overrunning clutch feature of the electric hoists was intended as a safeguard against an electric drive being left engaged and preventing automatic float operation of the gate. However, this feature leaves the operator powerless to lower a gate if one should become stuck in a raised position, or if some emergency should arise which might require reduction of flood release. I believe it is almost universally true that provision should be made for bypassing automatic equipment if the necessity arises. The case of the flood below Vallecito Dam in July 1957, is a very good example. (See Reference 4). Here the telephone line was out and operating personnel were trying to keep releases below flood stage through the night until people could be warned next morning. However, at 4:40 a.m. July 27, the automatic float controls took over, operators "lost control," the three spillway gates suddenly opened about 4 feet, and the spill increased from about 4,000 cfs to 12,000 cfs. There was some faulty judgment on the part of operating personnel; but if they had been able to maintain control, the damage would, undoubtedly, have been much less.

The clutch in the Cachuma hoists can be easily converted to a square jaw type which will drive in either direction, by welding up the sloping side of the jaws and machining them square. (See Drawing No. 368-D-320, Part 17.) Operators should be instructed to leave the clutches disengaged except when a gate is suspended thereon.

The discharge control orifices are now located at the bottom of the 36-inch float well header, where they could be plugged by submerged objects and cause the gates to open more than intended. These should be located at the center line of the header, elevation 715.50, and for the sake of accuracy and ease of machining, should be round instead of square. They would then be relatively safe from plugging by submerged or floating objects.

Proposed Alteration of Control Water Inlets

In order to remove the possibility of sending unprecedented floods down the river due to sticking of a gate or breakage of a weir cable as discussed above, and also to eliminate hunting of the gates, a

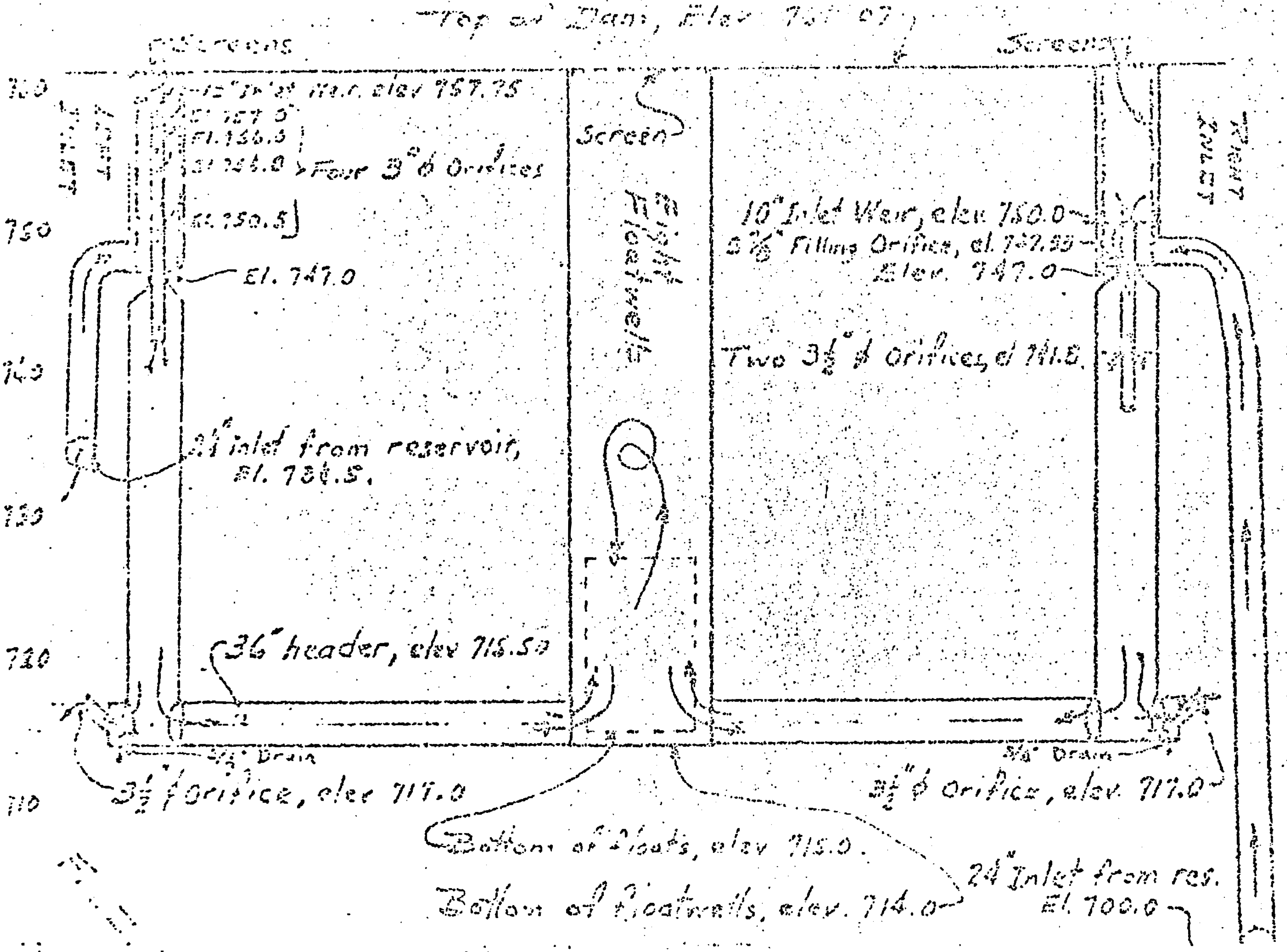


FIGURE 11

Cachuma Dam
Proposed Control for Spillway Gates

system of stationary inlet weirs and orifices has been worked out which will give the desired 1 to 4 ratio between reservoir surcharge and gage opening. The system provides a definite reservoir level to begin opening and to complete closing of the gates, a definite level to complete opening and to begin closing, and intermediate levels at which definite gate positions will be determined by inlet orifices. Inflows and outflows were calculated as follows:

1. Inflow over horizontal circular weirs,

$$q = 10.3 \; Dh^{3/2}$$

2. Flow through round, square-edged, vertical orifices,

$$q = CA \quad 2gh$$

Values of C were obtained from the data of Hamilton Smith, Jr. appearing in Le Conte's "Hydraulics" McGraw Hill, 1926.

3. Flow through round, vertical orifices flowing partially full was calculated from data presented by J. C. Stevens in the ASCE Journal of Hydraulics, December, 1957.

The following diagrams, charts, and tables are included to describe the proposed control system and its operation:

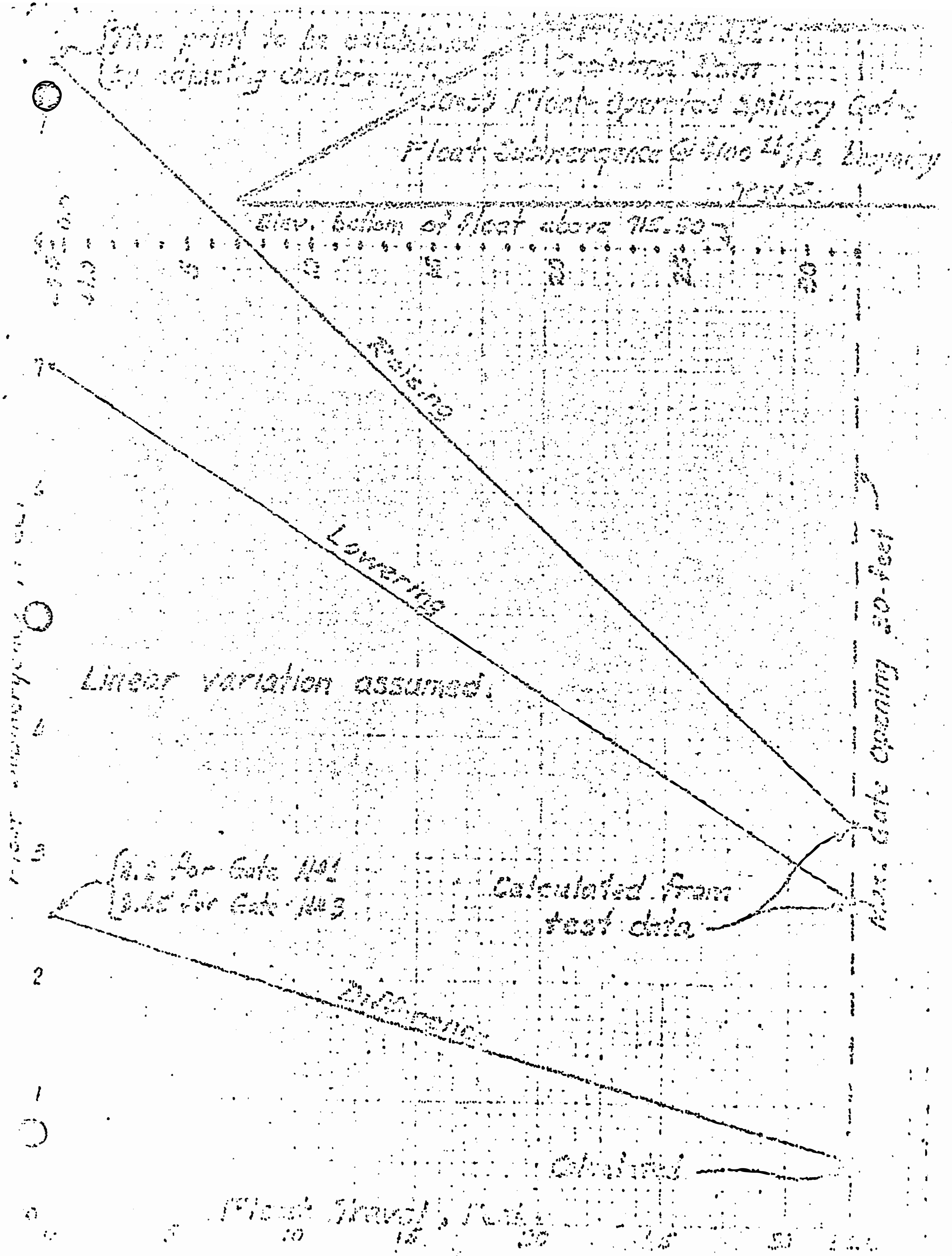
Figure II, Schematic diagram of proposed control system
Figure III, Determination of float submergence
Table II, Calculated control data
Figure IV, Gate position and float system water level and flow plotted as functions of reservoir water level

A description of the system follows:

1. Three feet would be added to the height of each float, making them 12.00 feet high, and bottom of floats would be at elevation 715.0 with gates closed.

2. Removable 1-inch mesh screens would be placed at the inlets of the weir wells. One-fourth-inch mesh screens would be welded over the bottom side of the cover grating of each float well and weir well.

3. Inlet weirs would be disconnected from the gate hoists and fixed at elevation 750.0 for the right weir and 757.75 for the left weir. The bottom end of the right weir downspout would



Raising
Lowering
Linear variation assumed.
Calculated from test data
Elev. bottom of float above
Gate Opening 30-feet
Float Travel, feet

be blinded off and two 3-1/2-inch round orifices would be installed in the vertical pipe wall at elevation 741.8. A 5-7/8-inch round inlet orifice would also be installed in the right downspout at elevation 747.33 for the purpose of rapidly filling the float system. The 5-7/8-inch orifice would not affect actual movement of the gates as control passes to the 3-1/2-inch orifices at elevation 741.8 before motion occurs. In the downspout of the left weir, four 3-inch round vertical orifices would be installed * * * one at elevation 750.5, one at 754.0, one at 756.0, and one at 757.0. All orifices would be machined in flat stainless steel plates and bolted to prepared seats on the outside of the existing 10-inch downspouts.

4. The outlet control orifices would be two 3-1/2-inch diameter orifices at elevation 727.0, the top of the 36-inch float system header. Two small 3/4-inch drain orifices are provided to prevent stagnation.

5. Sufficient weight (6,000 to 7,000 pounds) would be added to each main counterweight so the gates would begin to rise when the floats are submerged 9-1/2 feet, with reservoir water surface at elevation 750.

Action of the control would then be as follows:

1. Rising reservoir.--

(a) When the reservoir level reaches elevation 747.1, water will begin flowing into the control system through the invert of the 5-7/8-inch filling orifice in the right inlet. Most of the initial inflow will be effective in filling the system; but a small amount will be lost from the two 3/4-inch drain holes. Water begins flowing out of the two 3-1/2-inch metering orifices only after the 36-inch float system header has been filled.

(b) All water entering the right inlet must pass through the two 3-1/2-inch orifices at elevation 741.8 in the downspout; but these do not control the inflow until after the 10-inch diameter inlet weir is overtopped at elevation 750. Control of the inflow then passes from the 5-7/8-inch orifice to the two 3-1/2-inch orifices. When the reservoir water level reaches 750.3, the inflow to the float system will be sufficient to begin raising the gates.

(c) The existing 10-inch inlet pipe will be fixed in the left side of the spillway, with its crest at elevation 757.75, and having four 3-inch round orifices through its side at elevations 750.5, 754, 756, and 757. If the reservoir continues to rise, water will flow into the float system through each of these orifices, consecutively,

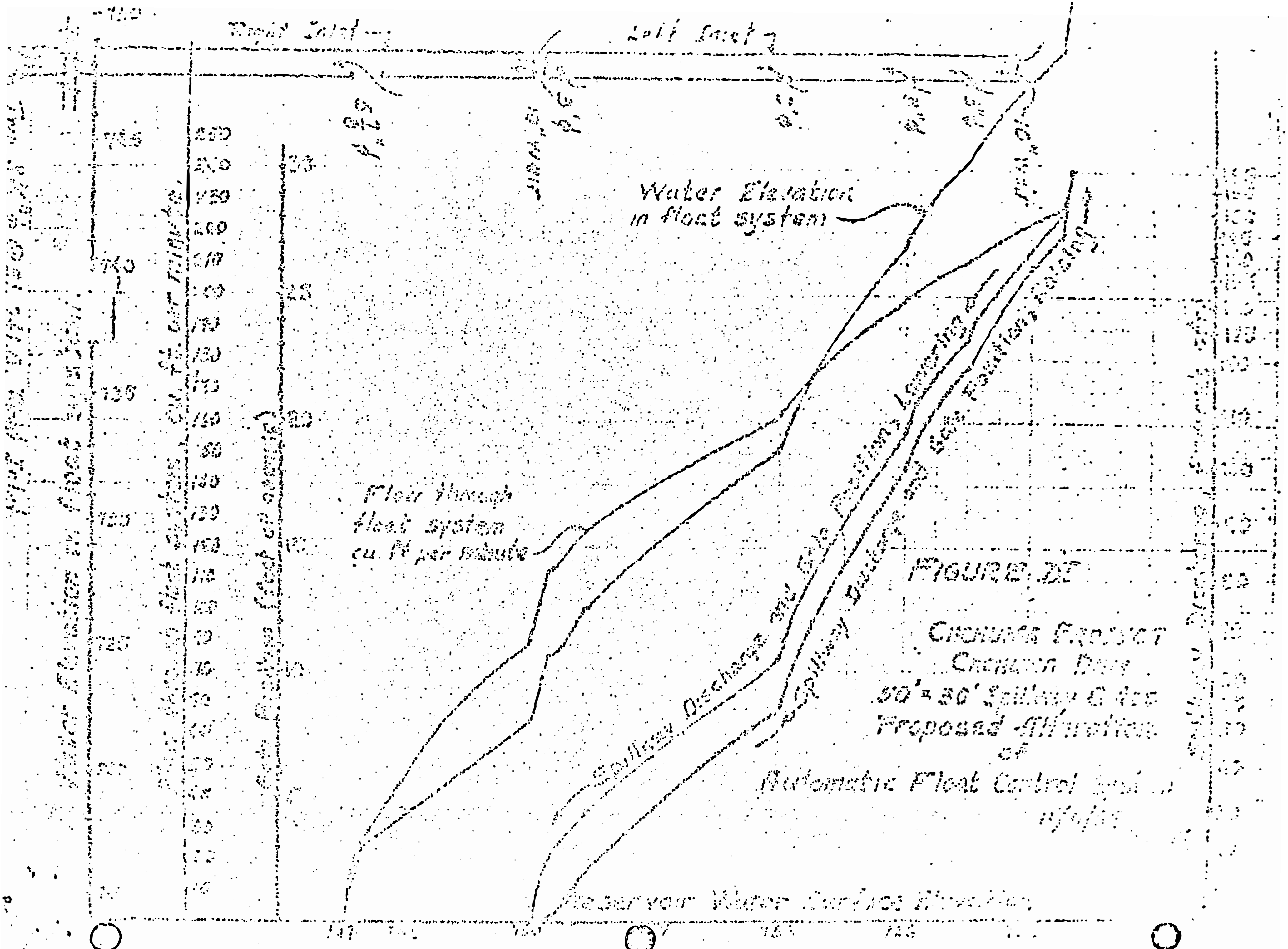


FIGURE XI

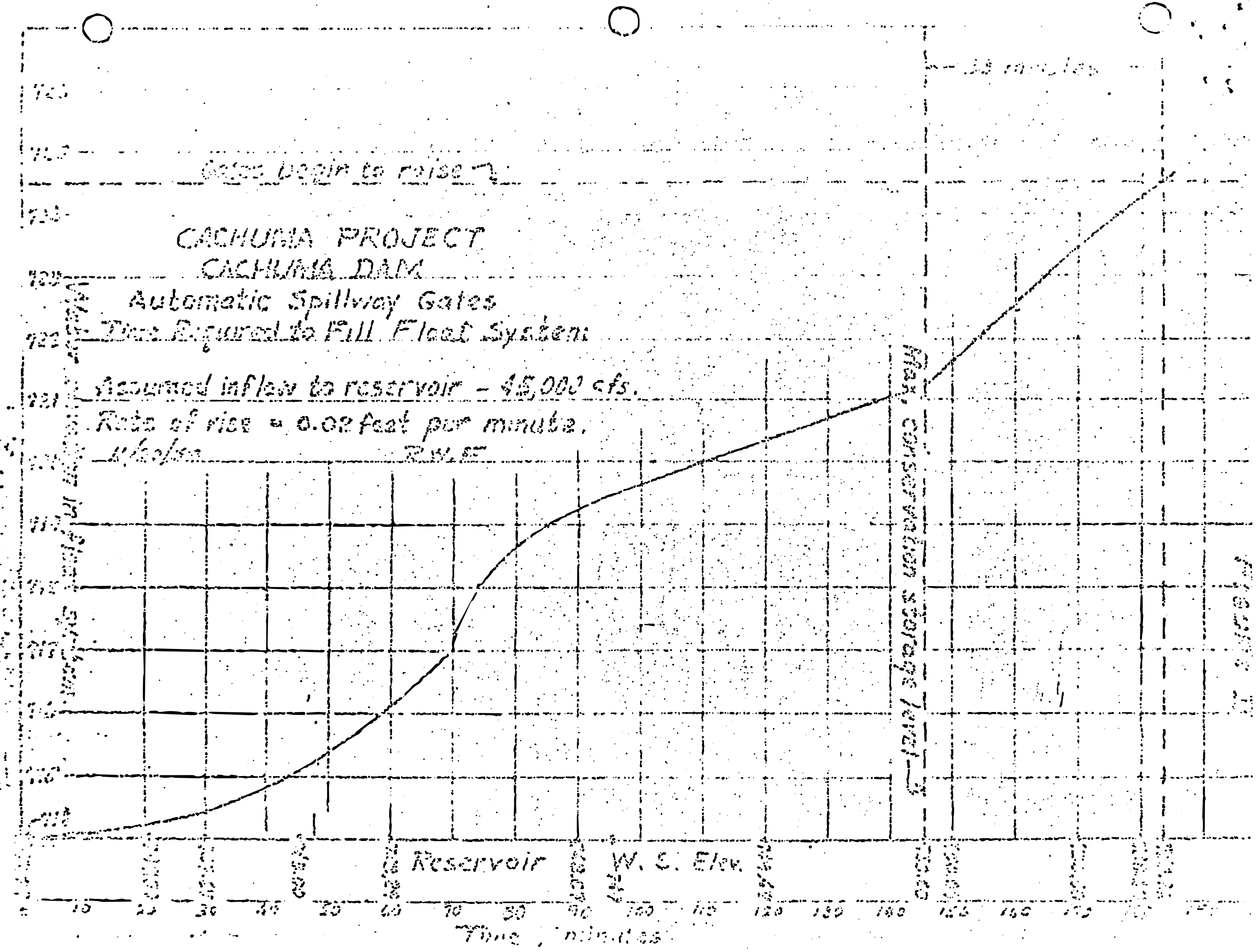
Crowns Project
Crown Dam
50' x 30' Spillway Gates
Proposed Alteration
of
Automatic Float Control

TABLE II

Coconuk Dam – Automatic Spillway Gates

CHARACTERISTICS OF PROPOSED ORIFICE CONTROL

Pool El.	Inflow to float system, CFM								Floated	Gate [illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Total	[illegible]	[illegible]	[illegible]
7[illegible]	0							0	714.0	0	0
7[illegible]	7.75							7.75	71[illegible]	0	0
7[illegible]	26.0							26.0	717.85	0	0
7[illegible]	45.0							45.0	718.17	0	0
7[illegible]	71.0							71.0	720.0	0	0
7[illegible]	88.5							88.5	721.5	0	0
750.[illegible]	78.5	16.5						95.0	722.5	0	0.[illegible]
750.[illegible]	58.0	46	104.0					104.0	723.6	0	1.5
750.3			112.0					112.6	724.6	0.1	[illegible]
750.[illegible]			116.7	4.5				121.2	725.9	[illegible]	[illegible]
750.[illegible]			116.8	5.9				12[illegible].7	726.5	2.0	[illegible]
751.0			116.3	10.0				126.3	726.7	3.2	4.[illegible]
751.5			114.8	14.1				133.6	728.0	3.[illegible]	5.7
752.0			122.[illegible]	17.2				139.1	729.[illegible]	4.[illegible]	[illegible]
752.5			125.5	20.0				145.5	730.0	5.[illegible]	7.[illegible]
753.0			128.0	22.4				150.4	731.0	6.[illegible]	7.[illegible]
753.5			131.5	26.5				156.0	732.[illegible]	7.6	9.[illegible]
754.0			134.0	26.5	1.5			162.0	733.1	[illegible]	10.5
754.5			136.5	28.3	10.0			174.8	735.5	12.0	13.[illegible]
755.0			139.2	30.0	14.[illegible]			183.6	737.[illegible]	1[illegible].0	15.[illegible]
755.5			142.0	31.6	17.3			190.9	739.4	[illegible]	17.[illegible]
756.0			144.4	33.1	20.0	1.5		199.0	741.0	[illegible]	19.[illegible]
756.[illegible]			139.0	33.6	22.4	10.5		206.0	742.[illegible]	[illegible]	[illegible]
757.0			134.6	36.0	21.5	4.1	1.5	210.7	744.4	[illegible]	[illegible]
757.5			126.8	37.4	26.5	17.3	10.0	215.0	74[illegible]	[illegible]	[illegible]
75[illegible]			121.6	31.7	28.2	22.5	[illegible]	223.5	747.25	[illegible]	[illegible]
758.5			110.5	40.[illegible]	30.0	27.[illegible]	[illegible]	228.2	74[illegible]	[illegible]	[illegible]
[illegible]			[illegible] 103.2	4[illegible]	30.3	[illegible]	[illegible]	225.5	750.6	[illegible]	[illegible]
[illegible]			[illegible] 101.5	[illegible]	29.8	[illegible]	[illegible]	[illegible]	750.[illegible]	[illegible]	[illegible]


CACHUMA PROJECT
CACHUMA DAM
Automatic Spillway Gates
Time Required to Fill Float System
Assumed inflow to reservoir - 45,000 cfs.
Rate of rise = 0.02 feet per minute.
Gates begin to raise
Float reservoir filled
Reservoir W. S. Elev.
Time, minutes

such changing in the inflow. The system is designed to open the gates slowly at first (about 2-1/4 feet for each foot of reservoir rise.) Then, after the reservoir passes elevation 754, the rate of opening the gates is accelerated so that they will be nearly wide open when the left inlet weir is overtopped. As this 10-inch diameter weir at elevation 757.75 is overtopped, the gates will open the remaining few inches; and when the reservoir subsides below the crest of the weir, the gates will begin to close. Laboratory model studies showed a drawdown of 0.75 foot with ungated spillway and reservoir surface elevation 755. Therefore, the reservoir water surface will be at approximately elevation 758.5 when the left weir is overtopped.

2. Declining reservoir

(a) Friction, principally seal friction, will require some decline of the reservoir before any downward movement of the gates from a previously attained opening will occur. (See Figure IV.) For example, if the reservoir peaked at elevation 752.0, the gates would reach an opening of about 4-1/2 feet and would remain there until the reservoir subsided to elevation 751, when the gates would begin to close. This difference becomes less as the gates open wider, due to decrease in seal friction as the gates lift out of the water.

3. Time required to fill the float system and begin opening the spillway gates in event of a rapidly filling reservoir:

Floyd Holdaway of the Dams Branch suggested the possibility of a flood crest coinciding with the time the reservoir fills, resulting in a rapid rise and necessitating prompt opening of the gates. The small surface area of Cachuma Reservoir makes this especially critical. For the purpose of design calculations, a 100-year flood of approximately 45,000-cfs peak was suggested by the Flood Hydrology Section. Accordingly, an inflow of 45,000 cfs was assumed as the reservoir approached elevation 750, the maximum conservation storage level. This would produce a reservoir rise of 0.02 foot per minute. It was calculated that the float system would be filled sufficiently to begin opening the gates in 38 minutes after the reservoir passed elevation 750; and in that time the reservoir would have risen to elevation 750.76. A 12-inch splash plate on top of the present gates would be sufficient for this condition. (See Figure V.)

Conclusions

1. The present automatic gate controls at Cachuma Dam are unsafe because:

(a) Sticking of either end gate could cause the other three gates to open completely with an increase of only 1/10 foot in reservoir water level, spilling about twice the historic flood.

(b) If one of the slender 3/16-wire ropes which suspend the control weirs were to break, and reservoir water surface were anywhere above 750.6, all four gates would open completely, spilling at least 115,000 cfs.

(c) If the gates are operating on float control and are open partially or fully, the operator is powerless to lower the gates at all with the electric hoist. This is because of the overrunning clutch by which the electric hoist is connected.

2. The present floats are not large enough to provide an adequate margin of safety for raising and lowering the gates. This is due to seal friction, hydraulic pressure downward on the bottom seal, and other unknown hydraulic forces. The causes of these forces will not be accessible until the reservoir is drawn down to elevation 720.

3. Setting the control weirs above the gate crests as they now are, creates another downward load when the water overtops the gates.

4. The moving or compensating weirs introduce a hunting action which is undesirable.

5. The present float control discharge orifices are in the bottom of the 36-inch header where submerged debris could clog them.

6. Screens have not been provided to keep debris out of the control system.

Recommendations

1. It is recommended that the control weirs be fixed, rather than moving, to eliminate the flood hazard and hunting which are inherent in the cable suspended weirs: one weir crest to be fixed at elevation 750.6 to establish the maximum storage level, the second weir to be fixed at elevation 757.75 to establish the maximum surcharge level. A system of fixed orifices to establish the desired ratio of gate opening to reservoir level is proposed herein.

2. It is recommended that the present overriding feature of the electric hoist clutch be eliminated by welding and remachining the clutch jaws, to enable an operator to bypass the automatic control if it should be necessary. (The Project has been instructed to do this for operation through the 1958-59 flood season, and it is recommended that the revision be permanently retained.)

3. In line with Mr. Polley's recommendations, it is recommended that the eight floats be increased in depth 3 feet each, and that 12 inches be added to the height of each gate to permit full storage at elevation 750.0 without danger of overtopping the gates.

4. It is recommended that the present 3-inch square discharge control orifices be blinded off, and new 3-1/2-inch round orifices be connected at header center line elevation 715.50, to reduce the likelihood of clogging.

5. It is recommended that screens be installed at the weir well inlets and under the weir well and float well gratings to keep out objects which might clog the orifices.

6. It is recommended that at such future time as the reservoir declines and makes the upstream faces of the gates accessible, consideration be given to changing bottom seal and side seal design to decrease friction and hydraulic forces which are detrimental to float operation of the gates.

H. E. SHEDA

Copy to: ~~210~~ 225
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"The recommended design of changes are approved."

/s/ L. G. Puls
2-3-59