UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

AN INVESTIGATION CONCERNING THE PROTOTYPE BEHAVIOR OF MORNING-GLORY SPILLWAYS

Hydraulic Laboratory Report Hyd-254

RESEARCH AND GEOLOGY DIVISION

BRANCH OF DESIGN AND CONSTRUCTION
DENVER, COLORADO

NOVEMBER 19, 1948

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Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
Date: November 19, 1948

Laboratory Report No. HYD-254
Hydraulic Laboratory
Compiled by: J. N. Bradley
Reviewed by: J. E. Warnock

Subject: An investigation concerning the prototype behavior of morning-glory spillways.

INTRODUCTION

In recent years, questions have been frequent regarding the merits and disadvantages of morning-glory shaft spillways. With the construction of the Heart Butte Dam Spillway, which will consist of a morning-glory designed for submerged flow with as much as 54 feet of head on the crest, and the design of the Hungry Horse Spillway, which will feature a total drop of 475 feet from headwater to tailwater, the old questions take on new significance. For example, vibration in the Heart Butte Spillway, which is embedded in poorly cemented sandstone, would create a serious situation. The possibility of erosion of the tunnel lining in the Hungry Horse Spillway by the high-velocity flow, produced by the unusually high head, also requires serious consideration.

In an attempt to partially clarify some of the questions in the light of prototype experience, a questionnaire was sent to persons connected with each morning-glory shaft spillway, of any size, known to exist throughout the world. This report constitutes an abstract of the findings acquired in this manner.

CHARACTERISTICS OF THE MORNING-GLORY SPILLWAY

The morning-glory shaft spillway is attractive in that it can often be constructed at a moderate cost when compared to other types, and it is adaptable to dams in narrow canyons. For free flow, the discharge characteristics for the morning-glory are similar to those for the straight overfall dam section; an increase in discharge being proportional to the three-halves power of the head. When operated submerged, the flow characteristics change completely, an increase in discharge then being proportional to the square root of the head, but the effective head in this case may exceed the head measured above the crest The salient difference is that once submerged flow occurs, a further increase in head results in a very limited increase in discharge. This feature is a distinct disadvantage over the free overfall type of structure and requires careful consideration, especially in this country where stream-gage records are not extensive so far as length of time is concerned.

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METHOD USED IN OBTAINING INFORMATION

The investigation consisted of first searching available literature for information on morning-glory spillways; then corresponding with persons familiar with these field structures. The pertinent details, such as name, location of spillway, maximum designed discharge, maximum head on crest, vertical fall, gate arrangement, diameter of tunnel, etc., are recorded on Table 1, together with references to engineering literature and source of information. Sketches and cross-sections of the spillways investigated are shown on Figures 1 and 2.

The following is the general text of the questionnare transmitted to each of the various engineer correspondents listed on Table 1:

"In connection with the design of recent large morning-glory spillways, an attempt is being made to obtain any pertinent information regarding the behavior of similar but smaller prototype structures in the field. We are particularly interested in any difficulties that have been experienced in the operation of the spillway under consideration over the period of years since its completion. In an endeavor to convey to you the type of information desired, the following questions may be helpful:

"a. Has any erosion of the concrete been experienced in the tunnel, especially in the vicinity of the vertical elbow?

"b. Has objectionable vibration ever been noticeable in the structure during operation?

"c. Has any difficulty been experienced in the passing of debris or ice?

"d. Has noise ever been sufficient to be objectionable?

"e. Has the shaft spillway ever operated submerged, and if so, were any objectionable conditions witnessed, such as cavitation erosion, objectionable vortices, etc.?

"f. Please mention any other unusual difficulties which may have been experienced in operation of the spillway proper.

"g. Have any reliable discharge measurements been made during operation of the shaft spillway? If so, a record of the discharges and corresponding reservoir elevations would be appreciated."

The response from this inquiry proved very gratifying, and the cooperation received from the various individuals was excellent. In only one case was a reply lacking: namely, that from the morning-glory shafts for the Bassano Power Canal in Italy. The difficulty here was in locating an individual familiar with the project. Correspondence was not attempted in the case of the spillway for the Sulak Dam in Russia for the same reason. It is doubtful whether the later dam has been constructed.

INFORMATION RECEIVED

The information received from all questionnaries is briefly summarized in Table 2. Although definite questions were asked in the questionnaries, the number varied depending on the spillway investigated. Where replies were merely stated in the affirmative or the negative, the only listing made is in Table 2. Where additional information was volunteered, this has been abstracted. The asterisks in Table 2 indicate that additional information is available on the subjects which they denote. The following pages are devoted to an abstract of this material.

Owyhee Dam (Owyhee Project, Idaho)

"The water surface in the Owyhee Reservoir reached the elevation of the crest of the spillway with the ring gate down on March 26, 1936, and spilling started. By March 31, 1936, the water surface in the reservoir was 0.8 of a foot over the crest of the ring gate. The gate was left in the lowered position until April 14, 1936, when it was raised and the flow shut off to permit inspection of the tunnel. Up to this time, the maximum discharge reached had been 7,600 second-feet and the total amount of water spilled was 55,000 acre-feet. On April 15, 1936, the gate was operated throughout its range and the operation was smooth and satisfactory and showed no disposition to drift. Flow over the spillway stopped on May 12, 1936. During the period from March 25 to May 12, approximately 300,000 acre-feet of water was wasted through the spillway, and the maximum discharge reached was about 15,000 second-feet.

"During 1936, the automatic controls on the ring gate released water faster than anticipated, and a large whirl, formed by the discharge from the spillway tunnel, washed out about 300 feet of fill in the canyon immediately below the dam and a railroad trestle. Additional cutting and some damage to the Owyhee Ditch Company diversion were experienced in later seasons. During the winter of 1938, the automatic controls were disconnected from the ring gate. The reason for this is illustrated in the following example:

> If 1,800 second-feet are being released (approximately 2 feet over the crest of the gate) and the wind blows downstream, wave action can cause the water surface elevation to raise as much as 0.1 of a foot, which in turn will raise the float and lower the gate as much as 1 foot, which would increase the discharge through the spillway to approximately 3,200 second-feet. This feature of the automatic control is not desireable as it must be watched with vigilance."

"In the spring of 1940, the automatic controls were again connected after adjustment to permit operation only near maximum reservoir elevation and then only in case of reservoir surface fluctuations of from 6 to 8 inches. During flows of 1.5 feet in depth over the crest, the water falls in a solid sheet toward the center of the spillway shaft, apparently entraining air there faster than it can be released at the outlet end of the spillway tunnel, causing the air pressure to increase until sufficient to break through the sheet of falling water. The air emerges with enough force to carry spray 50 or 60 feet above the level of the gate crest. This phenomenon occurs sometimes as often as once every 5 minutes, depending upon the tailwater elevation, which is influenced also by water released through the needle valve outlet. For flows less than the above-stated, the excess entrained air can apparently move back up the spillway shaft unhampered. For flows greater than 1.5 feet over the crest, the air pressure is not sufficient to break back; and it is forced out through the outlet end causing spray and water to be thrown high into the canyon.

"No evidence of flutter of the jet has been noticed, thus indicating that the air supply provided to the underside of the nappe through the 8-inch air pipes is adequate. Furthermore, no evidence of vibration has been apparent in the spillway tunnel. Inspections of the spillway, vertical shaft, the elbow, and the tunnel downstream have disclosed no indication of cavitation erosion or erosion of any kind. These inspections have been conducted annually since first operation of the spillway in 1936."

Since no mention is made of the effectiveness of the ice-prevention equipment installed near the spillway crest, it is assumed that it operates satisfactorily, or that it has never been necessary to use it. A plan and cross-section of the spillway are shown on Figure 1A and a photograph of the morning-glory in operation with 1.5 feet of head over the crest is shown on Figure 3A. A record of the model studies made in conjunction with the design of the Owyhee Dam Spillway is contained in Hydraulic Laboratory Report HYD-159, Bureau of Reclamation November 15, 1944.

Gibson Dam--Sun River Project, Montana

"The water surface in Gibson Reservoir reached elevation 4712.0 on May 21, 1938, which is the elevation of the crest of the concrete spillway. From May 21 to June 28 a total of approximately 435,000 acre-feet of water flowed through the morning-glory spillway. A peak flow of 13,100 second-feet occurred on June 4.

"In office letter of December 2, 1946, subject (Seepage conditions in spillway tunnel--Gibson Dam) it was mentioned that erosion had occurred in the tunnel and that the largest spot on the sides was about 30 inches horizontally, 18 inches vertically, and 2 inches deep in the center. It was concluded that this damage was caused by scaling due to freezing and thawing during the winter.

"Upon inspection of the tunnel on July 31, 1948, two spots about 5 feet in greatest dimension, oval in shape, and 2 inches deep, prominently displayed erosion. These eroded areas are on the side near the bottom of the vertical bend and about 3 to 5 feet above elevation 4550.0. which is the elevation of the invert of the level section of the spillway tunnel One of the areas exposed portions of two reinforcement bars, and the other one exposed a short piece of one bar. It is believed that these two eroded areas have existed for several years, but the water passing through the spillway in the 1948 season caused them to show additional erosion.

"Ice has always melted in place in the reservoir when the water surface has been below the crest of the spillway, consequently, no ice has passed through the spillway. Large trees, on the other hand, have passed through the spillway during flood seasons but never have caused trouble. The spillway when discharging a large head, produces considerable noise, but it is difficult to see why this should be objectionable."

The original morning-glory spillway, consisting of a free crest, (Figure 1-B) was completed in 1926. After several years of operation additional storage was needed. The morning-glory portion was revised in 1936 to embody radial gates and piers, as shown in Figures 1-C and 3-B. An account of the model studies made in connection with the revision can be found in Hydraulic Laboratory Report HYD-159, Bureau of Reclamation, November 15, 1944.

Figure 4 is a photograph of the vertical bend in the Gibson Spillway taken in September 1948. The erosion reported is inconsequential compared to the offsets and breaks in continuity of the surface produced by rough form work. This type of surface is no longer tolerated on new work where conduits carry high-velocity water. Rough surfaces and misalinements are conducive to rapid erosion of the surface at high velocities, as was evident in the Arizona spillway tunnel of Boulder dam;1/ while smooth surfaces show resistance to erosion at comparable velocities, as was shown by the spillway tunnel at Fontana Dam.2/ 3/ In both cases the tunnels consisted of both inclined and horizontal sections, and the discharges and velocities were comparable.

1/ Warnock, J. E., "Cavitation in Hydraulic Structures," Trans Am. Soc. C. E., Vol. 112, 1947, p 43.

2/ Reed, Oran, "Construction Procedures at Fontana," Civil Engineering, Vol. 16, No. 5, May 1946, p.210.

3/ Peterka, A. J., "Model and Prototype Studies on Unique Spillway," Civil Engineering, Vol. 16, No. 6, June 1946, p 249.

Guernsey Spillway--North Platte Project, Nebraska

"As the Guernsey Spillway has not been used over 200 hours during the past 19 years, very little information is available. Some erosion has occurred at the construction joints and the vertical bend of the tunnel, especially the upper portion. This probably could be avoided in new structures by using modern methods of placing concrete.

"No objectionable vibration has been noticeable in the structure during operation. No difficulty has been experienced in the passing of debris or ice. In fact, this spillway has chiefly been used for passing debris and has been quite satisfactory in this respect. Practically all flow regulation is accomplished with a 50- by 50-foot stoney gate on the left side of the dam. The maximum discharge recorded through the spillway is approximately 5,000 second-feet."

A section of the Guernsey Spillway is shown on Figure 1-E.

Davis Bridge Spillway, Vermont

"There has been no appreciable erosion of the concrete in the horizontal part of the tunnel. At the vertical bend there was a rough spot about 3 feet wide by 6 by 8 feet long with a maximum depth of, perhaps, 6 inches which was cut out and filled about 4 or 5 years ago. It is not certain whether this was caused by erosion due to discharge or erosion due to freezing and thawing of the concrete. In any event, it was a minor repair.

"All the ice and debris which has passed over the crest between the piers has readily gone through the spillway. Logs and trees 50 to 60 feet long have passed through the spillway at times. There is some noise when the spillway is in operation, but this can be heard only a short distance from the dam. The operator's house is the only dwelling within a mile or more of the spillway.

"No coefficients have been obtained from the prototype which could be compared with those used in the model tests. The spillway has discharged several times for short periods. The maximum discharge occurred in the September hurricane flood of 1938, when the water reached an elevation of 6.1 feet over the crest. The computed discharge at that time was about 19,400 second-feet. The spill during this September Flood exceeded 10,000 second-feet for about 15 hours duration."

A plan and section of the Davis Bridge Spillway is shown in Figure 1-F.

Kingsley Dam, Nebraska

"The curved section at the vertical bend in the morning-glory spillway is almost entirely submerged at all times. There has not been an occasion to dewater this tube and accordingly it is not known whether erosion has occurred. The maximum discharge through the structure has not exceeded approximately 3,000 second-feet, whereas its discharge capacity is rated at approximately 54,000 cubic feet per second.

"There has been no occasion to operate the spillway with ice or debris on the reservoir. No difficulties have been experienced in connection with operation of the tractor gates, however improvements could be made in the design of the gantry hoists."

Figure 1-H shows a plan and section of the Kingsley Spillway.

The Ladybower Spillway, England

"No erosion of the concrete has so far been experienced either in the tunnel or at the vertical bend. The object of the model study was to ascertain the difference between the behavior of the internally stepped form of design in contradistinction to one with smooth surface, as had usually been adopted in the past, since the former is much easier to construct and likewise cheaper. In the end, the step type proved to be less efficient than the other. The outcome was, in fact, slightly superior under maximum working conditions."

A plan and section of the stepped Ladybower Spillway is shown on Figure 2-J.

Silent Valley Spillway, Ireland

"Apprehension that erosion might occur caused the designers to line the vertical bend with cast iron."

Figure 2-M shows a section of this spillway.

Pontain Ketchil Spillway, Jahore, Malayia States

"This spillway is situated in the Malayan forest where cyclonic storms occur of such intensity as to uproot large trees and carry them for considerable distances. An emergency overflow was provided in case the bellmouth became partially blocked."

A sketch of this spillway is shown on Figure 2-N.

Burnhope Spillway, England

"The vertical bend in the tunnel is lined with cast iron. One record of a moderate flood is recorded at Burnhope involving a discharge of 1,440 second-feet. No undesirable operating conditions are on record."

A section of the Burnhope Spillway is shown on Figure 2-O.

Manuherikia Falls Spillway, New Zealand

"Erosion of the concrete has been experienced at or near the vertical bend of the tunnel and also more particularly at the crest curve in the vicinity of construction joints. It is suggested that construction joints be avoided at the crest.

"This spillway has not, until recently, passed a large flood, and for this reason we cannot at present give details of its operation under flood conditions. During the week of November 1, 1948, however, a severe flood was experienced in the region of the dam, and a request has been made for more information. This report may be sometime in arriving, but we will dispatch it, together with a report on the laboratory tests, as soon as they are available."

A cross-section of the Manuherikia Falls Spillway is shown on Figure 2-P.

Krauserbouten and Königreichwalde Spillways, Czechoslovakia

"These spillways have a rather ancient design and have rather small dimensions. Their internal diameter is 13 feet, and they begin to operate under a head of 85 feet from spillway crest to tailwater. The vertical shaft is lined with masonry in one case, and there is a right angle fin, while in the other, a transition. No erosion has been experienced at the vertical bend, and no very objectionable vibrations have been set up in the spillways during operation. No difficulties have been experienced with ice or debris, as these are not passed through the circular spillway but over a small normal overflow spillway. The spillways contain small piers which support a circular trashrack. There naturally is some noise during operation, but this can hardly be termed unbearable or very objectionable. In flood times the spillway operates submerged."

CONCLUSIONS

All correspondence received from this investigation is on file in the Hydraulic Laboratory of the Bureau of Reclamation.

The inference to be drawn from the foregoing is far from conclusive. Of the 17 morning-glory spillways investigated, information on one was lacking; two others have never gone into operation; and the majority of the remainder have operated for only short periods of time at discharges considerably less than that for which the spillways were designed, leaving approximately four which can be considered to have undergone a fair test.

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The most significant facts revealed from the investigation were:

a. That no erosion of the concrete was reported at the vertical bend at Owyhee Dam. This spillway has operated at approximately half capacity and has by far the greatest fall of any of the spillways in existence. In no case has erosion of a serious nature occurred on any of the spillways investigated.

b. That vibration and noise were not sufficient to be considered objectionable, and

c. That in no case has debris or ice presented any unusual problems in operation.

From a hydraulic standpoint, morning-glory shaft spillways appear to be of sound design when operated under entirely free flow conditions. The questionable factors are structural, such as, will the concrete or material composing the curved surfaces withstand the velocity and impact of the fast-moving water?

A point to be considered is that no spillway in this group has ever operated submerged. With submerged flow the spillway acts much like a siphon, and very low pressures can be experienced in the tunnel. These low pressures, if sufficient to reach the vapor pressure of water, can cause initial erosion of the tunnel lining by cavitation which is always accompanied by vibration and noise. Once roughened, impact by the jet of water can cause rapid erosion of the surface. As no record exists of hydraulic behavior for submerged flow through a morning-glory spillway, it will be well to continue to treat this condition of design with respect.

With the compilation of this data on morning-glory spillways as to size, location, etc., together with an established list of correspondents, it should not be a great task to repeat an inquiry of this nature some 5 or 10 years hence. Time should make possible more pertinent information and should reveal weaknesses in the morning-glory shaft design, should general weaknesses exist.

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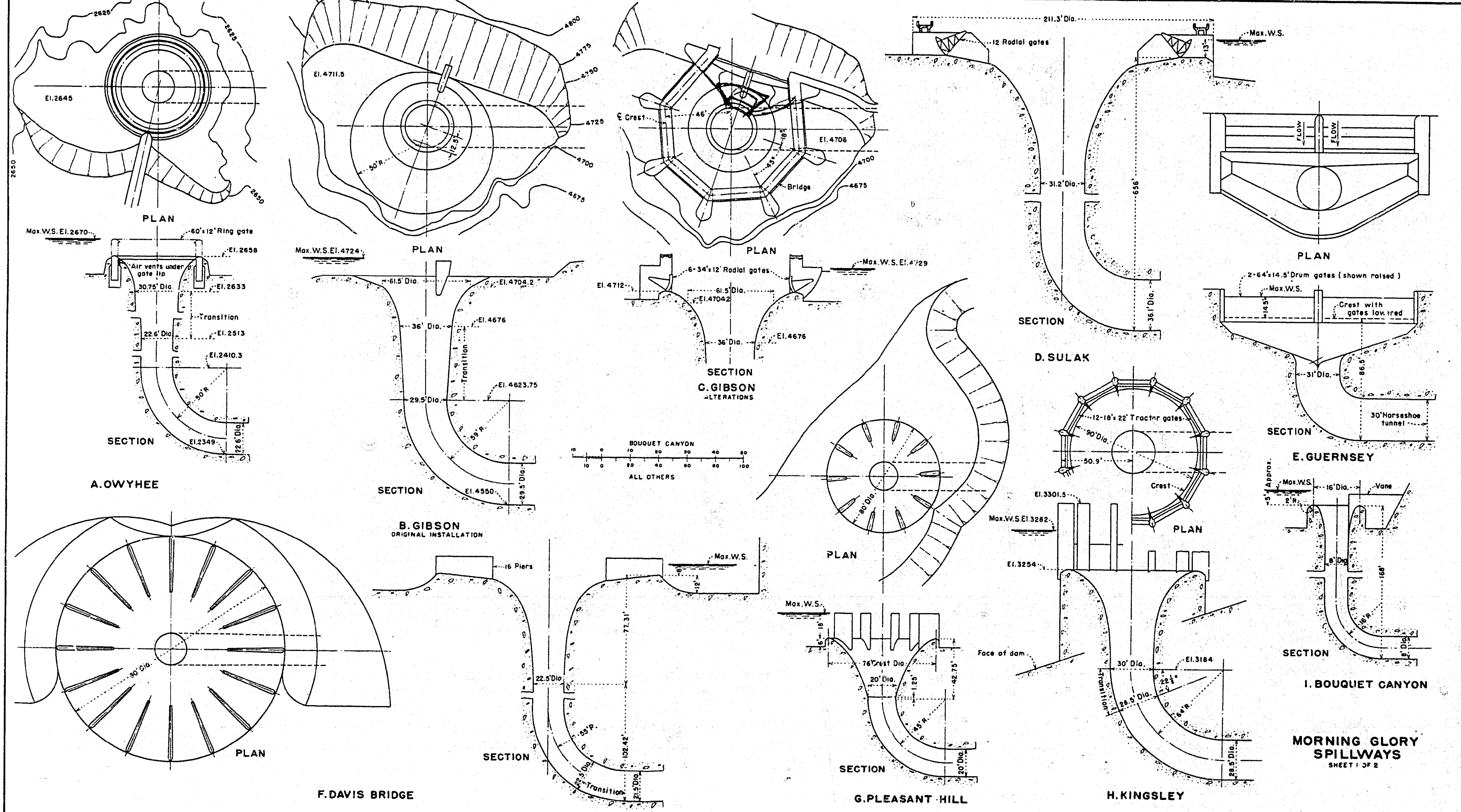
Mr. H. M. Nelson, New England Power Service Company,
Boston, Massachusetts

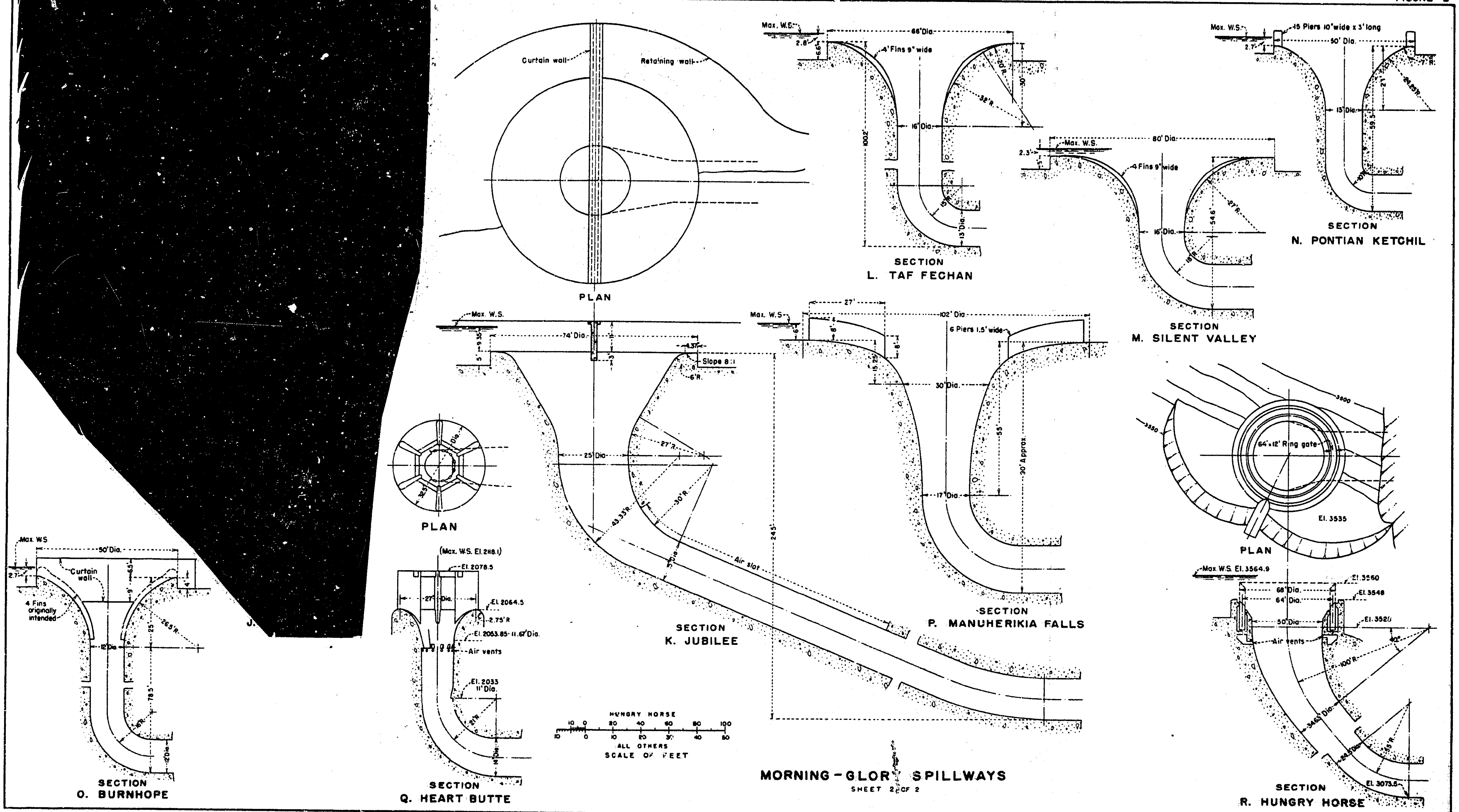
Mr. J. W. Ridley, Ministry of Works,
Wellington, New Zealand

FIGURE 1



MORNING GLORY SPILLWAYS
SHEET 1 OF 2

FIGURE 2



MORNING-GLORY SPILLWAYS

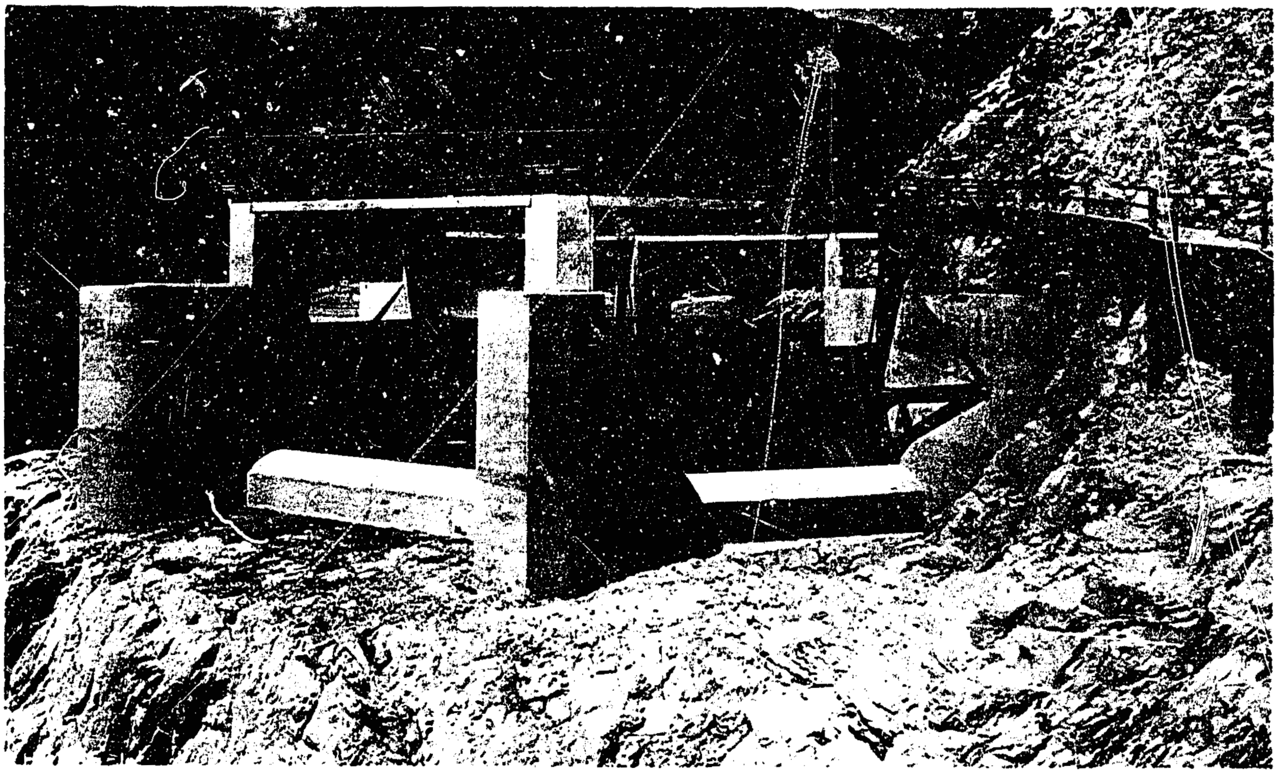
SHEET 2 OF 2

Table 1

COMPILATION OF MORNING-GLORY SPILLWAYS

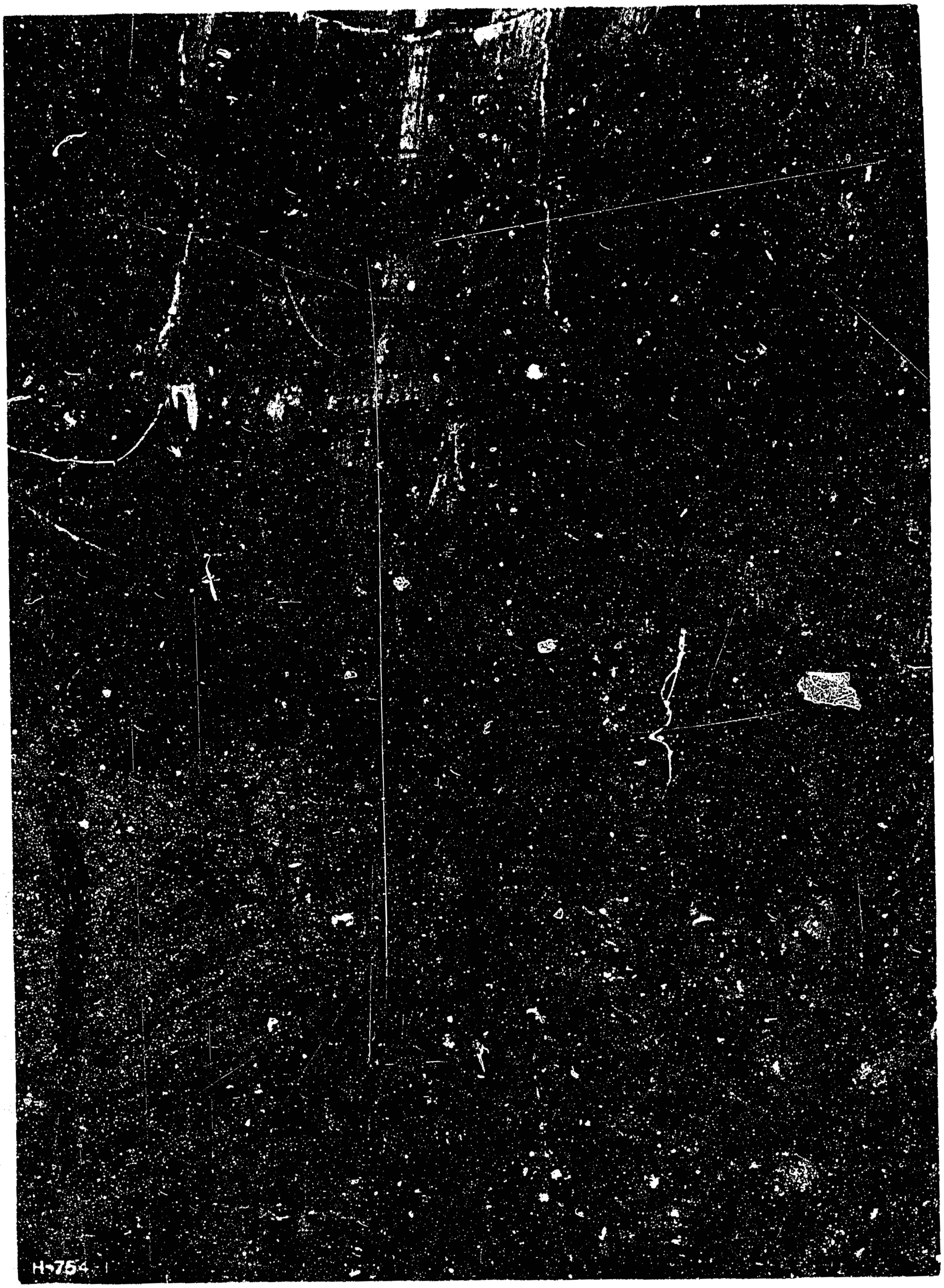
Name	Location	Maximum discharge (cfs)	Maximum head on crest (ft)	Fall—crest to invert of horizontal tunnel (ft)	Length of horizontal tunnel (ft)	Type of gates and number	Number of piers	Diameter of tunnel (ft)	Radius vertical bend (ft)	Remarks	References to literature	References for correspondence
Owyhee	Owyhee Project—Idaho	30,000	12	309	750	1 ring gate, 60' in diameter	1	22.6	50		Reclamation Era, Vol 30, No 8, Aug 1940, Page 226, Power Plant Engineering, Vol 37, Nov 1933, Page 482, HYD-159	Regional Director, Bureau of Reclamation, Boise, Idaho
Gibson	Sun River Project—Montana	50,000	17	162	350	6 radial gates in reverse position, 34' by 12'	6	29.5	59		HYD-159, Dams and Control Works, 1929, Page 79	Regional Director, Bureau of Reclamation, Billings, Montana
Sulak	Russia	60,000	13	656	2,510	12 radial gates	12	36			Engineering News-Record, October 17, 1935	
Guernsey	North Platte Project—Nebraska	30,000	14.5	86.5	750	2 drum gates, 64' by 14.5'	1	30' horseshoe		Gates on only one side of morning glory	Dams and Control works, 1929, Page 55	Regional Director, Bureau of Reclamation Denver, Colorado
Davis Bridge	On Deerfield River near Whitingham, Vermont	27,000	8	180	600 approx	None	16	21.5	55		Trans ASCE, Vol 88, 1925, Page 1	H.M. Nelson, New England Power Service Co., 441 Stuart Street, Boston 16, Mass.
Pleasant Hill	Mohican River near Perrysville, Ohio	16,000	18	98	680	None	10	20	45		Hydraulic Model Studies for Pleasant Hill Dam, May, 1935, Case School of Applied Science	Division Engineer, Ohio River Division, Corps of Engineers, U. S. Army, 536 U. S. Post Office Bldg, Cincinnati 1, Ohio
Kingsley	North Platte River near Ogallala, Nebraska	54,000	28	148	723	12 tractor gates, 18' by 22'	12	28.5	64 approx		Report on Hydraulic Model Studies, Kestone Dam, Nov 1936, Case School of Applied Science	Chief Engineer, Central Nebraska Public Power and Irrigation District, Hastings, Nebraska
Bouquet Canyon	Bouquet Creek, 50 miles from Los Angeles	6,900	5 approx	168	1,280	None	1 vane	8.0	16		Civil Engineering, Vol 4, No 8, Aug 1934, Page 393	Chief Engineer, Dept of Water and Power, City of Los Angeles, Los Angeles 54, California
Ladybower	Derwent River in Derbyshire, England		10	122	700 each	None	12	15	35	Stepped glory hole—Two spillways—Both horizontal tunnels have sharp bends	The Engineer, Vol 168, Nov 3, 1939, Page 440	G. H. Hill and Sons, 51 Mosley St., Manchester 2, England
Jubilee	Hong Kong	16,800	9.35	245	640	None	Curtain wall	15			Experiments on Bellmouth and Siphon Bellmouth overflow spillways, by Geoffrey Morse Binnie, Journal Institute of Civil Engineer, Vol 10, Nov 1938, Page 65	W. J. E. Binnie, Binnie, Deacon and Gourley, Artillery House, Artillery Row, Victoria Street, Westminster, S.W. England
Taf Fechan	Wales	3,040	2.8	100		None	4 fins below crest	13	15		Trans of the Institute of Water Engineers, Vol XLII, 1937, Page 103	W. J. E. Binnie, Binnie, Deacon and Gourley, Artillery House, Artillery Row, Victoria St., Westminster, S.W. England
Silent Valley	Ireland	2,600	2.3	54.6		None	4 fins below crest	16	18		Trans of the Institute of Water Engineers, Vol XLII, 1937, Page 103	W. J. E. Binnie, Binnie, Deacon and Gourley, Artillery House, Artillery Row, Victoria St., Westminster, S.W. England
Pontian Ketchil	Jahore	2,700	2.7	59.5		None	15	13	10		Trans of the Institute of Water Engineers, Vol XLII, 1937, Page 103	W. J. E. Binnie, Binnie, Deacon and Gourley, Artillery House, Artillery Row, Victoria St., Westminster, S.W. England
Burnhope	Durham County, England	2,630	2.7	103.5		None	2 fins curtain wall	12	16		Trans of the Institute of Water Engineers, Vol XLII, 1937, Page 103	W. J. E. Binnie, Binnie, Deacon and Gourley, Artillery House, Artillery Row, Victoria St., Westminster, S. W. England
Manuherikia Falls Dam	New Zealand	19,400	6	90 approx		None	6	17			Trans of the Institute of Water Engineers, Vol XLII, 1937, Page 103	J. W. Ridley, Hydro-electric Design Office, Ministry of Works, Wellington, New Zealand
Bassano Power Canal	Northern Italy	1,138 for 3 shafts	2.46	60 approx		None	None	8.4		Three shafts	Giornale del Genio Civile, July 31, 1917, Page 341	
Heart Butte	North Dakota	5,600	53.6	59.5	625	None	6	14	21	Under construction		Regional Director, Bureau of Reclamation, Billings, Montana
Hungry Horse	Montana	53,000	16.9	475	526	1 ring gate, 64' by 12'	1	24.5	55	50° sloping tunnel proposed	Preliminary design	Regional Director, Bureau of Reclamation, Billings, Montana
South Holston	South Holston River, Tennessee	61,000				None	6	34	75	Under construction		Chief Engineer, Tennessee Valley Authority, Knoxville, Tennessee
Watanga	Watanga River, Tennessee	61,000		290		None	6	34	75	Under construction		Chief Engineer, Tennessee Valley Authority, Knoxville, Tennessee
Kreuserbonden	Czechoslovakia	3,500	3.5					16.5			Trans ASCE, Vol 88, 1925, Page 77	P. Novak, c/o T. G. Masary National Hydrological Institute, Prague XIX, Podbaba, Czechoslovakia
[illegible]	Czechoslovakia	4,000 and 2,500								Two shaft spillways	Trans ASCE, Vol 88, 1925, Page 77	P. Novak, c/o T. G. Masaryk National Hydrological Institute, Prague XIX, Podbaba, Czechoslovakia

A. Owyhee Dam Spillway-illustrating updraft of spray when operating at approximately 1,200 c.f.s.



B. Gibson Dam Spillway-showing arrangement of radial gates and piers

MORNING-GLORY SPILLWAYS



GIBSON DAM SPILLWAY-SHOWING DISCONTINUITY AND EROSION AT VERTICAL BEND.

Table 2

PROTOTYPE BEHAVIOR OF MORNING-GLORY SPILLWAYS

Questions	Owyhee	Gibson	Guernsey	Davis Bridge	Pleasant Hill	Kingsley	Bouquet Canyon	Ladybower	Jubilee	Taf Fechan	Silent Valley	Pontian Ketchil	Burnhope	Manuherikia Falls	Bassano Power Canal	Krauserbouden	Königreichwalde
(a) Has erosion been experienced at or near vertical bend in tunnel?	No*	Small amount*	Small amount*	Minor amount*	Has never gone into operation	Uncertain*	Has never gone into operation	No	No	No	No*	No	No*	Yes*	Information lacking	No	No
(b) Has vibration been noticeable during operation?	No*	No	No	No		No		No	No	No	No	No	No	No		No	No
(c) Has difficulty been experienced in passing ice or debris?	No	No*	No*	No*		No*		No	No	No	No	No*	No	No		No	No
(d) Has noise been sufficient to be objectionable?	No	Quite noisy, not objectionable*	No	No*		No		No	No	No	No	No	No	No		No	No
(e) Have piers or curtain walls proven as effective as anticipated?	Yes			Yes				Yes	Yes	Yes	Yes	Yes	Yes	Yes			
(f) Has spillway ever operated submerged?	No	No	No	No		No		No	No	No	No	No	No	No		Uncertain	Uncertain
(g) Have any difficulties been experienced with gate operation?	Yes* on automatic	No	No			No*											
(h) Have any head-discharge measurements been made?	No*	No*	No*	One*		No*		No	No	No	No	No	No*	No*		No	No
(i) Other difficulties experienced during operation.	None	None	None	None		None		None	None	None	None	None	None	None		None	None

*Indicates additional information available in the text.