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UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: DIGEST OF REPORT OF COMMITTEE ON MADDEN DAM (ALLEHUELA) PROJECT

HYDRAULIC LABORATORY REPORT NO. ..09

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by

E. W. LANE

Under direction of

TECHNICAL MEMORANDUM NO. 120

Denver, Colorado

February 14, 1930

(PRICE $1.80)

Denver, Colorado, February 14, 1930

Memorandum to the Chief Designing Engineer
(E. W. Lane, Research Engineer)

Subject: Digest of Report of Committee on the Madden Dam (Alhajuela) Project, January 4, 1928.

Introduction

1. The report digested herein* was made by a committee appointed by Maj. F. C. Harrington in accordance with instructions issued by him. The report was submitted January 4, 1928. Many details of the project were left partially developed, to be worked out by the designing engineer when borings and detail maps became available. For this reason several subjects in the report are left open, the report consisting of a compilation of studies and opinions on various phases of the project, for use in the final design of the project.

Hydraulics of the Project

2. As a result of its studies, the committee decided (1) that the reservoir should be held to a normal operating level at elevation 240, (2) that storage space was necessary to reduce flood peaks and recommended a maximum flood level of 255 to 260, the exact level to be decided by the designing engineer when further data became available, and (3) that the final design should provide for a discharge of not less than 50,000 second-feet at the normal elevation of 240. These decisions were based upon the following facts:

From Memo. No. 1. Spillway Capacity Must Exceed 170,00 Second-Feet.

If no storage to reduce peaks is provided, 170,000 second-feet discharge must be provided for. The dry season starts from the 5th to the 15th of December. In order to enter the dry season with a maximum

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*Only portions of report pertinent to design of dam digested.

water supply it will be necessary to have the reservoir full at this time. Every major flood of record occurred in November or December, and therefore at a time when the reservoir would be full or nearly full. Therefore capacity either for the discharge or the storage of these floods must be provided. The Gatun spillway was designed for a 24-hour flow of 137,500 second feet and the designing engineer believed the maximum peak rate of inflow into Gatun Lake would be 170,000 second feet. In the past 16 years the discharge exceeded 100,000 second feet three times, and once reached 154,000 (possibly 170,000). There is no site available for a 170,000 second foot spillway.

From Memo No. 2. Chagres River Floods. The annual maximum floods in the Chagres River at Alhajuela since 1905 are shown in the following table:

Year	Max. Alhajuela Ht. Ft. above Sea Level	Max. Momentary Discharge (c.f.s.)	Max. 24-hour Discharge (c.f.s.)
1906	119.30	101,000*	58,900*
1907	104.30	38,800	22,100
1908	101.50	26,500	16,900
1909	121.00	154,000	100,100
1910	108.70	63,400	28,400
1911	105.50	47,400	18,450
1912	108.40	52,550	31,350
1913	103.78	34,000	17,200
1914	103.10	31,200	15,200
1915	104.32	38,450	19,000
1916	101.55	24,850	8,900
1915	107.95	49,200	27,300
1918	110.00	61,000	30,100
1919	101.30	24,200	8,100
1920	103.20	28,950	13,000
1921	102.10	24,750	16,850
1922	104.80	33,050	21,750

Annual Maximum Floods (Continued)

Year	Max. Alhajuela Ht. Ft. above Sea Level	Max. Momentary Discharge (c.f.s.)	Max. 24-hour Discharge (c.f.s.)
1923	117.42	108,300	73,400
1924	102.95	32,800	17,100
1925	100.15	21,450	12,037
1926	101.96	25,345	11,910
Average	106.35	48,600	27,000

*On account of this flood destroying the stations and no actual gagings being taken, it is believed (in view of 1909 and 1923 measurements) the 1906 estimates were much too low.

It shows peak rates of from 21,450 to 154,000 second feet averaging 48,600 second feet and maximum 24 hour discharges of 8,100 to 100,100 second feet, averaging 27,000 second feet. The ratio of the 24-hour rate to the peak rate is therefore 55%. In freshets which rise and fall rapidly, such as usually occurs at the beginning of the rainy season, the ratio is nearer 30%, but for large floods it is nearer 65%, giving a ratio of peak floods to 24-hour floods of 1.53. The 197 floods which occurred between November, 1906, and July, 1927, give ratios of 27 to 86%, with an average of 50%, as compared with 55% as obtained from the annual maximum floods.

The Fuller formula (maximum 24-hour discharge = average annual maximum 24-hour discharge x (1+0.8 log T), where T is the average interval between floods of that size) cannot be applied directly to the Chagres River. From the data on this river, a formula of the same form would be: Max. 24-hour = ave. annual max. 24-hour (1+1.83 log T).

Applying this formula, assuming the ratio of peak to 24-hour flow at 1.53, as determined above, gives the following as the probability of floods at Alhajuela:

Time	Maximum Discharge of Flood to be Expected. c.f.s. Momentary	24-hour
1 year	41,300	27,000
5 years	94,200	61,600
10 years	117,000	76,500
25 years	147,200	96,200
50 years	170,000	111,100
100 years	192,800	126,000
400 years	240,000	156,000

The one and five-year floods of this table seem too high, but the 50 and 100-year frequencies are not unreasonable.

A study of the records of the 48 years beginning 1879 indicates alternate periods of high and low floods, beginning with 12 years of high floods, then 15 years of low floods, followed by 5 years of high, then 12 years of low and ending with 4 years (or more) of high floods.

From Memo No. 3. Retention Volume Necessary. The purposes of the Madden Dam (Alhajuela) project in order of importance are:

(a) Increased water storage for dry season lockages, and incidental power production at Gatun, if practicable.

(b) Flood control to obviate the necessity of excessive use of Gatun spillway to regulate the height of Gatun Lake.

(c) Power production at Alhajuela.

(d) Prevention of excessive currents in the canal channel at Gamboa. (This is of minor importance).

It is believed a proper retention space will solve both the flood control problem (b) and excessive currents (d). It is proposed to build the dam to hold water to elevation 260, with elevation 240 as the ordinary high water storage level and 50,000 second-feet (at elevation 240) capacity sluiceways (including power plant discharge). That additional spillway capacity be provided (presumably at a saddle or saddles) for a super flood.

The storage in the reservoir is sufficient to hold 126,000 second-feet for 24 hours (the 100-year flood) without outflow between elevations 240 and 260. If a 50,000 second-foot outflow is allowed, the ordinary high storage level could be 247.6 instead of 240. The floods of the Chagres usually last over 24 hours. Using the 1909 flood, greatest observed flood, (peak flow 154,000 second-feet, maximum 24-hour flow 100,100 second-feet) assuming the reservoir at elevation 240 at the beginning of the flood, and a 50,000 second-foot discharge beginning at the start of the flood, the maximum level in the reservoir would be 248.6. The assumptions are impractical, as it will not be known until several hours after the flood starts that it is a great flood, and therefore the 50,000 second-foot discharge cannot begin at the start of the flood, since the gates would not be opened then. Moreover, in the case of a maximum flood, the capacity of the Gatun gates may be required to discharge the runoff below Alhajuela, and it may be necessary to store the entire flood runoff above Alhajuela for 24 hours before the 50,000 second-foot discharge into the Gatun Lake would be safe. With these assumptions, the 1909 flood would have reached elevation 256.55. A later study shows that the 1909 flood would reach 249.5 with 50,000 second-feet fluices, and if all gates were kept closed, would reach elevation 260 about midnight of the second day (41 hours after start of flood). There is always a possibility of another flood before the reservoir is empty, or that some time later elevation 245 may be taken as the ordinary storage level. It is therefore desirable to provide additional discharge facilities, which can probably be done at the saddles (elevations 219 to 256) by means of overflow spillways, flashboards, Tainter gates or siphon spillways. The United States has no lands above elevation 260 and no topography has been taken of higher lands. With a high storage level at elevation 240, the supply would be sufficient for the canal for 48 lockages per day, the capacity of the present locks. The results obtained in the canal operation for various numbers of lockages in wet and dry years are shown on the following table:

Use of Water for Various Number of Lockages

	Without Alhajuela Reservoir		With Alhajuela Reservoir	
	Dry Year	Wet Year	Dry Year	Wet Year
20 lockages per day in 1930				
Gatun Lake elevation, close of dry season	80	80	82.4	80
Power load carried	1/2 Gatun 1/2 Miraflores	All at Gatun	All at Gatun	All at Gatun
Wasted at Gatun spillway (1,000,000,000 cubic feet)	none	27.4	none	3.6
Storage in Alhajuela at close of dry season (1,000,000,000 cubic feet)	——	——	none	Full (23.8)
32 lockages per day in 1941-42				
Gatun Lake elevation, close of dry season	80	80	A 84.5 B 80	C 84.5 D 80
Power load carried	All at Miraflores	All at Gatun	A Alhajuela or Miraflores B All at Gatun	C Gatun with Alh.&Miraflores in dry season D Half at Gatun
Wasted at Gatun spillway, B.C.F.	none	9.7	A & B none	C 6.4 D None
Storage in Alhajuela at close of dry season, B. C. F.	——	——	A & B none	C & D Full (23.8)
48 lockages per day in 1955-56				
Gatun Lake elevation, close of dry season	No data given Probably impossible		e 80 f 81	81
Power load carried			e 1/5 Gatun 4/5 Alh. Mir. f All at Alh. & Mir.	All at Alh. and Mir.
Wasted at Gatun spillway, B.C.F.			none	none
Storage in Alhajuela at close of dry season			none	none

From Memo. No. 4. Normal Annual Cycle for Controlling Madden Lake.

A study was made of the operation of the canal with the Madden dam built for 1914 to September, 1927, inc., assuming 48 lockages per day (using water-saving methods in dry periods), with 1500 second-feet capacity of Alhajuela power plant, taking out at elevation 180. The assumptions are a bit fictitious in (a) that the lockages would not be 48 per day as soon as the dam is built, and (b) it is based on a knowledge of discharge which would not be available to the operator at the time decisions on methods of operation were necessary.

The dry season starts with Madden Lake at 240 and Gatun at 87, most of the power being developed at Madden dam. There is a minimum of 1500 second-feet available at Madden dam, but in very dry years it is necessary to draw more than 1500 second feet to maintain the Gatun Lake level. In no case was it necessary to draw Madden Lake below elevation 180 or Gatun below 81.5. The wet season power load can be carried either at Gatun or Alhajuela but in very dry seasons the Miraflores plant has to carry part of the load.

The water demand for lockages assumes 3900 second-feet in wet season and 3420 second-feet during dry periods, the latter figure being less due to the use of water-saving methods. These methods will only be necessary in very dry periods. The 48 lockages is based on full use of water, the restricted use decreases somewhat the number of lockages possible.

The Miraflores power plant will be required to carry peak loads and for emergencies. At rare intervals it will be necessary for it to carry the entire load from June to September. The maximum rate available in dry periods from Madden Lake is 1500 second-feet but eventually the demand for power will exceed this. In wet seasons the load can be carried either at Gatun or Madden, giving great flexibility.

The construction of the Madden dam will increase the wastage at Gatun, since power will be generated there which will replace power from Gatun and thus the water which would generate this power at Gatun must be wasted. However, as the use of the canal increases, the waste will decrease, but with maximum traffic in wet years it may discharge continuously eight months, in dry years one or two months. In most years there will be some waste at Alhajuela, but only at rare intervals will it reach 50,000 second-feet. The Chagres River above the dam furnishes 40% of the runoff at Gatun and 60% in dry seasons.

<u>Memo. No. 5.</u> <u>Possible Seepages through Rims of Madden Lake.</u>

There are known to be caves and crevices along the Puente, Azota, Caballo and Marcelito. A fairly complete set of tests have been made to determine the possibility of leakages. The only thing which could have been overlooked are additional caverns in the Rio Puente, but this river watershed lies almost entirely in Alhajuela Lake. The Queb. Marcelito is a disappearing stream; its outlet is unknown; it may drain into the Azota Caballo or the Chagres, but in either event it will be in Madden Lake. The only point of danger is at the headwaters of the Azota Caballo, which is near the watershed of the Rio Chillibrillo, and the saddles in the ridge near the damsite. In either case the leakage would go to Gatun Lake. A study of the bank of the Azota Caballo up to the Chillibrillo Divide failed to show seams, holes or disappearing streams. A study of the watershed between saddles 5 and 6 failed to show holes or disappearing streams. The committee was not permitted to do exploratory work, but suggested careful study when the sites of the saddle dams are uncovered.

Memo 6, 6A and 6B. Power Installation. The power house should be a part of the west end of the main dam, on account of more freedom from trash and flood interference with tailwater levels. The power house would be 110'x40'* with floor probably at elevation 125

*100' long with three units 25'cc. 30' wide from downstream face of dam at elevation 115.

(but possibly as high as elevation 135 using longer turbine shaft and intermediate steady bearings). There would be three vertical single runner units 30'cc (the runner at elevation 115 or not too high for tailwater at elevation 95), with concrete draft tubes, and penstocks not over 9' in diameter, probably steel lined to provide housing for penstock valves and connection to turbines. The maximum penstock pressure at elevation 115, with a 2-second governor stroke and the lake at elevation 260, would be 72 pounds per square inch. Auxiliary apparatus, switch gear, and step-up transformers housed at elevations above 115, the transformers possibly outside. The penstock entrances can be any elevation not exceeding 165. In deciding the elevation, consideration should be given to (1) freedom from drift. A Stoney gate about 12,500 second-foot capacity, with sill at elevation 130 and top at elevation 150, was suggested to pass drift, (2) freedom from clogging with silt deposit, (3) facilities for cleaning racks and bulkheading the entrances.

The water allowed for power development is assumed at 1500 second-feet at no particular head. The lake level will vary from elevation 240 to elevation 180, which, with tailwater at elevation 95 gives heads from 145 to 85. The turbines should develop their best full load efficiency at 110 feet, and will be subjected to 30% greater and 23% less head. The turbine discharges will be as follows:

	Lake at El. 240 Head 145 ft.	Lake at El. 205 Head 110 ft.	Lake at El. 180 Head 85 ft.
Normal load 0.85 gate	1,710	1,500	1,315
Max. load 1.00 gate	2,020	1,765	1,550
Power at full gate 80% efficiency (Not including 5% transmission loss)	17,000kw.		9,000kw.

To average 1500 second-feet discharge, the discharge rates will be several hundred second-feet above these figures. With operation at part gate on higher heads and full gate on low heads, efficiencies within 6-7% of the maximum will be maintained. The power at elevation 180 is just sufficient for present (September, 1927) normal loads. Diesel engine power will be required on peaks when the lake falls below elevation 210, unless the Gatun plant is operating. Since the dam construction will involve construction of the penstocks and draft tubes, it will be advisable to build the power house at the same time as the dam.

The construction power demand will be approximately 2,000 kw. The construction of the permanent transmission line to the site for use during construction is recommended. It is suggested that the plant generate at 6600 volts, with three 6600-44,000-volt, 7500-kva. transformers at $25,000 each. Since the construction load is only 2000 kw., it is suggested that the construction power be obtained by using a 2300-44,000-volt, 2667-kva. transformer borrowed from and returnable to the Miraflores substation. The only other equipment required would be oil circuit breaker and lightning arrester, costing $5,000. At damsite temporary 2200-volt overhead construction will be required, with distribution transformers for low-voltage equipment.

In order to build the necessary portions of the power house at the same time as the dam, it is necessary to work out the power plant plan. The plan given is on the unit principle, each unit consisting of a 7500-kva. at 0.80 power factor, 6600-volt generator, direct connected exciter, and 8,000-horsepower vertical reaction turbine, with 7500-kva. 40° C. rise transformers situated outside. Synchronizing and transfer facilities obtained with a single 6600-volt bus and a single 44,000-volt bus. Duplicate transformer capacity for local light and power is provided, also a storage battery for emergency control purposes. The switchboard panels and controlling devices to be situated on the generator floor, for one-man operation.

The cost estimate is as follows:

3 - 8000-hp. turbines at $75,000 -		$ 225,000
3 - 7500-kva. generators & exciters at $75,000 -		225,000
3 - 7500-kva. transformers at $26,660 -		80,000
3 - 300-amp., 44,000-volt circuit breakers 2 - 400-amp., " " " "	at $2,500	12,500
1 - 50-ton overhead crane -		20,000
Miscellaneous equipment -		23,500
Building and structures -		500,000
Total		$1,086,000

Memo. No. 7. Devices for Regulating Alhajuela Lake. In order to conform to the requirements of flood level elevation 255-260, normal operating level 240, and discharge capacity of 50,000 second-feet at elevation 240, four classes of water passages at the dam will be required: (1) penstock for power, (2) sluicing gates for removing deposit and draining lake, (3) regulating culverts for supplying water to the canal, (4) flood wasteways, and possibly gate to pass drift.

The penstock discharge should not be included in the 50,000 second-feet, but might be valuable if any of the gates stuck. For sluiceways for gravel and lake drainage, 4 - 6-foot diameter culverts at river bed level (center at elevation 93) with 6'x6' conventional gate valves are suggested, which would discharge 7,700 second-feet with lake elevation 240. For regulating culverts to supply water for the canal, there are suggested 2 - 6' culverts high enough to be clear of gravel and drift (elevation 150). These would discharge 3,280 second-feet with lake at elevation 240. For flood wasteways, two sluice gates 50' high, 37 feet wide, with bottom at 210 (similar to those at Guernsey dam). These would discharge 39,220 second-feet with lake at elevation 240, making, with the sluice and regulating gates combined discharges as follows:

At lake elevation 240, - 50,160 second-feet
250, - 72,980 " "
260, - 96,920 " "

The two regulating valves will discharge 1900 second-feet with the lake at elevation 180, and the four sluicing gates will dis-sharge 1900 second-feet at elevation 102, thus practically all water in the lake can be drawn out as fast as the canal requires.

The lake can be drained from elevation 180 in 9 days with an inflow of 1,000 second-feet, and 13 days with an inflow of 2,000 second-feet, using the sluice and regulating gates. The average dry season inflow is 1,248 second-feet; in a very dry season it averaged 300 second-feet for 1-1/2 months, and in a very wet season it averaged 2,000 second-feet for a month. Draining should be done at the end of the dry season, and will require heavier spilling than ordinary into Gatun Lake.

It does not appear practical to recommend location for surface spillways. If constructed on top of the dam, an expensive apron will be required, and if at a saddle, the apron would probably be less expensive. Both wind and current would tend to carry drift to saddle No. 3, which appears most promising to discharge drift. If discharge from saddle reaches the river too abruptly it may create a dam of debris which would cause backwater at the power plant. A wide, flat approach to the river would dissipate the energy, and would be possible from saddles 3 and 4 but not 8.

Each valve should have bulkhead guides on the upstream face of the wall. The regulating gates should have a fine trash rack and the sluicing gates coarse ones to keep out logs. An operating tunnel should run over all valves to permit removal of the parts. Either hydraulic or electric operation should be provided.

Memo. No. 8. Program for Construction Period. The cofferdams are designed for a flood of 50,000 second-feet. It is proposed to build two 20'x20' sluiceways through the dam to handle the water during construction. If sufficient gravel can be obtained adjacent to the dam to construct these sluiceways a cofferdam (Fig. 1) GHIJ will be constructed around the site of the sluiceways. If gravel must be obtained from the river bed above the dam, cofferdam ACB must be constructed (to form a pool above the dam for the gravel dredges) with channel KLN and temporary sluice gates to control the pool level. When the sluiceways and dam within cofferdam GHIJ are completed, the ends of the cofferdam GHIJ can be removed, the channel LN closed and the cofferdam IF built. This will divert the river flow through the sluiceways and allow the river bed to be laid dry for the construction of the dam. It will probably be desirable to keep the sluiceways open nearly to the completion of expensive. Both wind and current would tend to carry drift to saddle No. 3, which appears most promising to discharge drift. If discharge from saddle reaches the river too abruptly it may create a dam of debris which would cause backwater at the power plant. A wide, flat approach to the river would dissipate the energy, and would be possible from saddles 3 and 4 but not 8.

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The quantities of concrete in the dam are as follows:

	Total to Upper Elevation
El. 62.0 to El. 110.5 - 92,300 cu. yds.	92,300
110.5 " " 159.0 - 94,000	186,300
159.0 " " 207.5 - 62,400	248,700
207.5 " " 256.0 - 30,300	279,000

<u>Memo. No. 11.</u> <u>Additional Investigations Needed.</u> Field investigations are needed for:

(1) Sanitation of area adjacent to damsite.

(2) Construction camp.

(3) Construction camp vs. quartering men in towns and transporting them to dam in trucks.

(4) Water purification plant.

(5) Storage of cement in large sheds at damsite vs. storage in box cars at Summit and hauling.

(6) Determine whether present shop and mill facilities can handle bulk of this work required.

(7) Careful study of types of equipment to be used.

(8) Practicability of three eight-hour shifts.

(9) Force account vs. contract.

(10) Survey of damsite with adjacent areas, also saddles.

(11) Cross sections up and down-stream from dam and saddles.

(12) Determine geodetic coordinates.

(13) Photographs taken at known locations, both from ground and air with other points of known location showing.

(14) Survey of channel below saddles 1, 2, 3, 4, and 8.

(15) Determine how much of lake area should be cleared of trees, and whether the area can be burned.

(16) Further consideration of seepage at head of Aceta-Caballo River.

(17) Core borings on damsite and saddles.

Borings on center line of dam 100' apart.

Borings 100 and 200 feet above and below center line 200' apart.

Borings on center line of saddle dams 100 to 200' apart.

Borings 100 feet above and below axis of saddle dams 200-300' apart.

Wash borings may supplement core drillings if desirable.

(18) Cores should be classified geologically and tested for crushing strength.

(19) Porosity of rock formation should be determined.

(20) Bearing pressure tests should be made on foundation.

(21) Locate, estimate yardage and test all gravel beds available for aggregate.

(22) Locate and test material suitable for cobble rock for use in concrete of dam.

(23) Locate and test material in quarries available for furnishing road metal for roads to saddles.

Miscellaneous Information from Minutes of Committee Meetings Not Given in Memoranda Submitted.

Meeting of October 27, 1927.

Gravel for Concrete.

There was estimated to be 200,000 cubic yards of gravel in the vicinity. That there was plenty along the river up to Vigia. Estimates were based upon gravel above water level, although much was believed to lie below that level. It was believed that it could be brought down in barges. No suitable rock was known adjacent to the river.