UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: EXISTING ROCK-FILL WEIRS

ON

PERVIOUS FOUNDATIONS

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HYD 4.1

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INTRODUCTION

In connection with the design of the Imperial Dam for the diversion of the waters of the Colorado River into the All-American Canal which will irrigate the Imperial Valley of Southern California, the possibility of using a rock-fill weir was considered. The Laguna Weir, which is of this type and is located five miles below the site of the Imperial, has been in operation for over a quarter of a century and has been very successful. In order to thoroughly study the possibilities of this type for the Imperial Dam site, the following report was drawn up covering data taken from all available sources.

The rock-fill, or Indian, weir has been used extensively for a long time. Some of those in India are over 1500 years old. This type of weir is fundamentally a diversion dam for irrigation works and for this reason is often referred to as a dam although weir is the more correct term. In Egypt, two of these dams have been built on branches of the Nile River delta. The Laguna weir, on the Colorado River, is the only large one of this type in the United States. In recent years, the rock-fill weir has been used only to a slight extent.

Figures 1 and 2 show the cross-section of weirs of this type on which records could be found. Figure 1 includes those which use a rubble facing on the sloping surface, and Figure 2 those which have a pav i surface of concrete or masonry. Tables 1, 2, and 3, and Figure 3 give other pertinent data.

The rock-fill weir is used primarily on rivers having pervious and easily erodible beds, and is adapted only to low flat streams of the type found in India. The nature of the weir and the foundation warrant its use only where the static head on the dam and the energy to be dissipated per lineal foot of crest during flood are small. From Table 1, it will be seen that the maximum height the water level is raised by these existing structures is not over 13 feet and that the flood drop over the crest is usually small. From an economical standpoint with respect to both construction and maintenance, abundant supplies of heavy stone and sufficient unskilled labor should be available at low cost.

Much of the theory with regard to underseepage and to hydrostatic uplift pressures which was used in the design of these works has been disproved in recent years. There is still considerable difference of opinion on certain points such as the effectiveness of vertical creep compared to horizontal, and more work in the way of experiment and the testing of actual dams is desirable. (1)

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(1) See references #4 and 7 in Bibliography.

ROCK-FILL WEIRS----RUBBLE FACING.

This type of rock-fill weir (see Figure 1.) has a breast wall which is filled on its down-stream side by a long slope of rock having a packed rubbled facing over which the water flows. The rock is retained in position by core walls of masonry which form cells into which the stone is packed. Weirs of this class are usually restricted to coarse sand foundations.

This is probably the oldest type of dam in existence, some of those in Madras Province, India, being over 1500 years old. The structure contains but little cut stone or mortar and consequently can be erected where skilled labor is hard to obtain. However, it is costly as the volume of stone used in the fill is enormous and the dam requires continual maintenance. ((2)

The Okhla Weir.

The Okhla Weir is constructed on very fine micaceous sand, and is said to have the greatest cross-section of any weir of its type in India. The stone used in the packing is very large, some blocks being as big as 6' x 3' x 2½'. The weir was badly damaged by the first floods which passed over it before it was completed in 1871, and large quantities of rock had to be thrown in below the talus of the weir and below the head-sluices which were nearly carried away, a hole some 50 feet deep being scoured out at the end of the floor.

Buckley ((3) states that the action of the flood is undoubtedly accentuated by the high sloping apron. The velocity over the crest of the weir in this flood was 9.3 feet per second, but that over the talus, where the damage occurred, was estimated to be over 16 feet per second.

The discharge of the river in high flood is only about 150,000 second feet (a unit flood discharge of 140 sec. ft.),* but the weir obstructs more than half the original waterway of the river, and the afflux (flood drop) is consequently high. The action on the weir slope is therefore very severe, even though the floods rise slowly and fill up the reach below the weir before any severe strain is brought on it.

Buckley ((4) cites the Okhla Weir as an example of what

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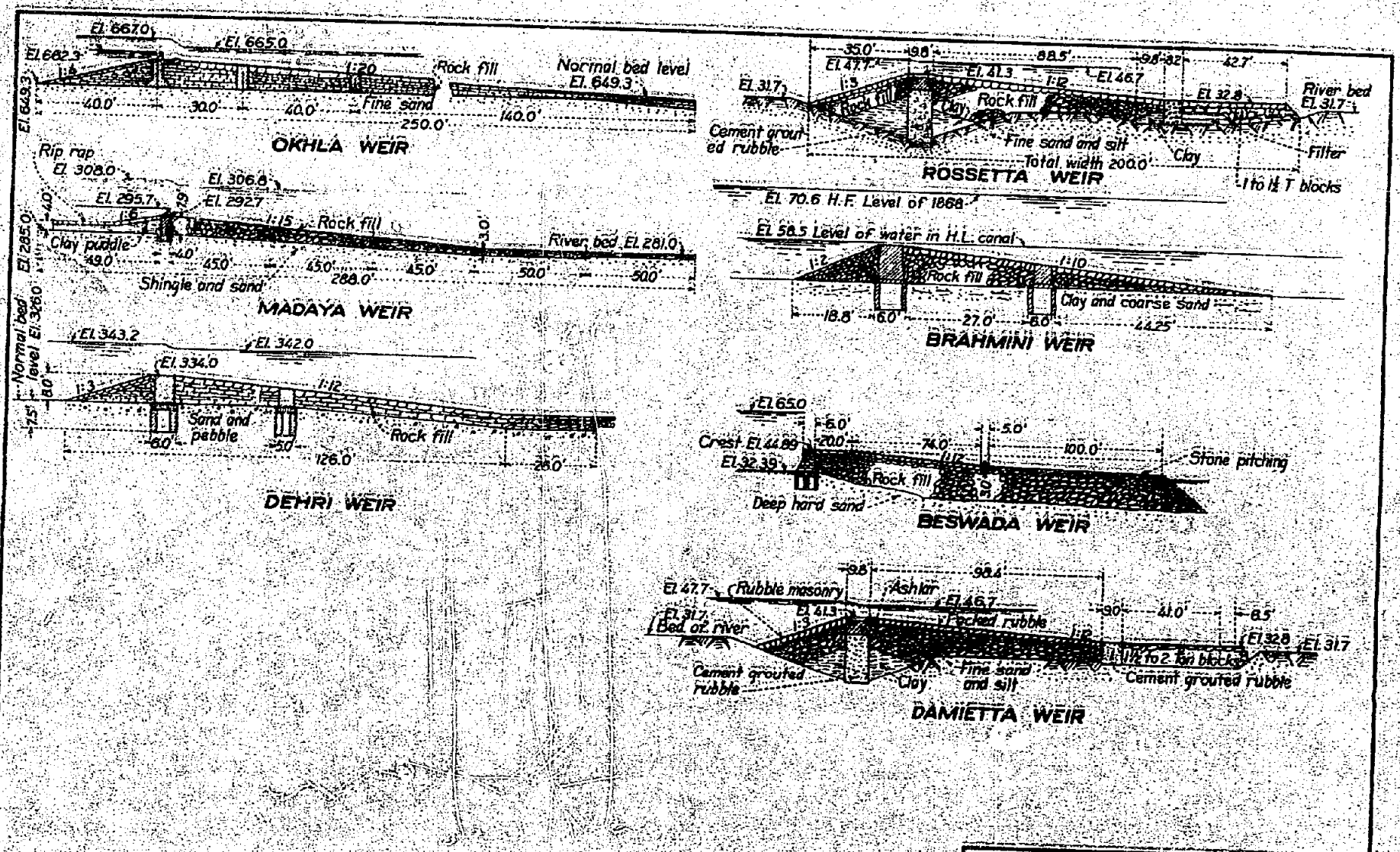
(2) See reference #6, p. 673.

(3) See reference #3, pp. 157, 166, 167.

(4) See reference #3, p. 175.

* Unit flood discharge is the discharge in sec. ft. per ft. of crest length.



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DENVER OFFICE

ROCK FILL WEIRS-RUBBLE FACING ON EARTH FOUNDATIONS

DRAWN: A.H.N. SUBMITTED:
TRACED: A.H.N. JGM RECOMMENDED:
CHECKED: APPROVED:

DENVER, COLO., JAN. 8, 1935

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DESIGNATION OF WEIR	LOCATION OF WEIR	CANAL	RIVER	DATE OF CONSTRUCTION	COST OF CONSTRUCTION	ANNUAL MAINTENANCE % OF ORIGINAL COST	RIVER BED MATERIAL	PLAIN CREEP-HEAD RATIO FOR RIVED BED	HEIGHT OF WEIR FEET	CREST BUTTER HEIGHT FEET	CREST LENGTH FEET	CREST WIDTH FEET	BASE WIDTH FEET	UPSTREAM SLOPE OF WEIR	DOWNSTREAM SLOPE OF WEIR	UPSTREAM WIDTH OF WEIR FEET	DOWNSTREAM WIDTH OF WEIR FEET	NUMBER OF CORE WALLS	UPSTREAM FLOOD-HEAD ON CREST FEET	DOWNSTREAM FLOOD-HEAD ON CREST FEET	FLOOD DROP OR AFFLUX - FT.	MAXIMUM FLOOD DISCHARGE C.F.S.	UNIT MAXIMUM FLOOD DISCHARGE C.F.S.	MAXIMUM FLOOD ENERGY DISSIPATED IN H.P. PER LINEAL FT. OF CREST
OKHLA	DEHLI, PUNJAB, INDIA	AGRA	JUMNA	1871			FINE SAND	15	10	3	2572	4	250	1:4	1:20	40	210	3	7.7	5.7	2.0	150,000	140	31.8
MADAYA	SEDAW, BURMA, INDIA	MANDALAY	MADAYA				SHINGLE AND GRAVEL	12	11.7	3	250	4	288	1:6	1:15	51	237	5	15.3	14.1	1.2	70,000	280	38.2
DEHRI	DEHRI, BEHAR, INDIA		SONE	1870-1874	RUPEES 1,490,368 *		SAND AND PEBBLE	12	8	2¼	12,469	5	152	1:3	1:12	26.5	125.5	2	9.2	8.0	1.2	830,000	66	9.0
ROSSETTA	BELOW CAIRO, EGYPT		NILE				FINE SAND AND SILT	18	9.6			9.8	200	1:3	1:12	40	160	2	6.4	5.4	1.0			
DAMIETTA	BELOW CAIRO, EGYPT		NILE				FINE SAND AND SILT	18	9.6			9.8	200	1:3	1:12	40	160	2	6.4	5.4	1.0			
BESWADA	BESWADA, MADRAS, INDIA		KISTNA	1854-1855		1.5	DEEP, HARD SAND	12	12.5		4,000	6	205	1:0	1:12	3	202	2	20.1			889,000	223	
BRAHMINI	ORISSA PROVINCE, INDIA		BRAHMINI				CLAY AND COARSE SAND		9.4			5	102	1:2	1:10	22	80	2						
JOBRA	JOBRA, ORISSA INDIA		MAHANADI				CLAY AND COARSE SAND	12	13	3	6,400	5	177	1:3	1:12	32.5	144.5	3	11.5	9.5	2.0	900,000	140	31.8
ADIMAPALLI	MADRAS PROVINCE, INDIA		PENNER	1870	RUPEES 456,233		SAND AND ROCK	12	8.5		2,243	4	201	1:9	1:11.75	25	176	3	18.37			413,552	184	
RUPAR	RUPAR, PUNJAB, INDIA	SIRHIND	SUTLEJ				SAND, SHINGLE AND SMALL BOULDERS		9.5	6	2,400	10	160	1:3	1:15	29	131	3				133,000	55	
GODAVERI	MADRAS COAST, INDIA		GODAVERI	PREVIOUS TO 1844			PURE SAND	12	11		12,000	15	265			40	225	2	18.9			1,200,000	100	
MON	MAZALI, BURMA INDIA		MON	1911					10	4	790	6	256	1:3	1:16.46	34	222	5						
SANGAM	SANGAM, MADRAS, INDIA		PENNER				SAND	12	10		4,076	4	205	1:15	1:12.5	62	143	4	12.5			597,600	147	
NELLORE	NELLORE, MADRAS, INDIA		PENNER	1859				12	5.0		1,581	5	273	1:4	1:26	38.5	234.5	3				600,000	380	
NELLORE (REBUILT)	NELLORE, MADRAS, INDIA		PENNER	1874				12	9.0		2,042	5	310	1:11	1:26	77.5	232.5	5	19.3			600,000	300	
HUANG PI	HUANG PI, CHINA		HU TUO HO	1934	$126,890 CHINESE		SAND AND GRAVEL		7.66		1,424	9.84	152.55	1:3	1:12	26.57	126.0	3			3 **	140,000	98.3	33.5
LAGUNA	ABOVE YUMA, ARIZ., U.S.A.		COLORADO	1909	$2,101,374 U.S.	0.4	VERY FINE SAND **	15	10		4,800	5	244	1:2	1:12	40.5	203.5	3	5.3 5.7	2.5 2.8	3.0 6.5	190,000 185,000	39.6 38.5	13.5 37.2

NOTES

Dam height measured from downstream low-water level as datum.

* Cost includes sluices, etc., for entire headworks.

** See discussion in text of report.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DENVER OFFICE

COMPARATIVE DATA ON ROCK-FILL WEIRS

DRAWN R.K.V. SUBMITTED
TRACED D.M.S. RECOMMENDED
CHECKED H.R. D.R. APPROVED

DENVER, COLO., SEPT. 17, 1935 X-D-1685

TABLE 1

can be done in the way of constructing a weir without any depth of foundation, even in extremely friable soil, provided there is ample heavy material available to resist the high velocity and great erosion in the lower slope, and provided the flow of the stream can be constantly maintained at right angles to the weir. Strong currents parallel to the face of light foundations are very disastrous. In this case, it should be noticed that the floods rise slowly, and there is less danger of any sudden alteration in the main currents. The stability of this weir has no doubt been considerably increased by the deposits of silt which have occurred above it, and which have tended greatly to prevent any probability of serious percolation under the weir.

The Madaya Weir.

As a result of the exceptionally heavy unit flood discharge (280 second feet), conditions for the Madaya Weir are quite out of the ordinary. Although the material of the river bed is shingle and coarse sand, the width of the talus exceeds even that of the Okhla Weir. In Bligh's (5) opinion, another type of weir with a vertical drop would probably have been better. By means of the increased area of the waterway thus provided, the velocity of flow would have been reduced and the scour materially lessened. This would have allowed economies in repairs and renewals, and might have reduced the talus width.

Bligh notes that the upstream apron has been well designed of impervious clay puddle, well protected on the surface and at its junction with the crest wall.

The Dehri Weir.

The bed of the Sone River here is deep sand with occasional layers of small pebbles. The Dehri weir is very long (12,469 feet). Although it obstructs about one-half of the former waterway of the river, the afflux has been calculated to be only about 15 inches.

The total cost of construction, which includes all sluices, etc., of the head-works, was 1,490,368 Rupees. The cost of closing the center sluices, and making their cross-section that of a weir, was 16,000 Rupees, but it proved to be an economical measure. (6)

Bligh (7) feels that the long lines of curtain walls

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(5) See reference #2, pp. 193-194.

(6) See reference #3, pp. 150-154.

(7) See reference #2, p. 189.

could probably have been safely dispensed with if the upstream apron had been reliably stanched in order to throw back the incidence of pressure and increase the effective base length, if three more body walls had been introduced, and the 1 to 12 slope retained, but the base should have been dredged out towards the apex to admit no thickness under 5 feet. This probably would not have increased quantities, except for masonry, over what they are now, and would have obviated entirely nearly 5 miles of undersunk block curtain walls.

The Rossetta and Damietta Weirs.

The core walls of the Rossetta and Damietta weirs were constructed under water by the grouting system. The weirs are very strong structures, and are practically watertight, there being hardly any filtration perceptible below them. The "Beresford's filter" was used; it tends to prevent the action of water in undermining a talus or floor. The system consists of an inverted filter laid on the sand. The bottom layers are formed of a substantial wedge of very fine stone ballast broken to the size of peas; above that is small rubble, then larger rubble, and then the pitching. The fine ballast or gravel allows any filtration water to pass freely, but by dissipating the velocity, prevents the passage of any particles of sand. This stops the undermining action of springs. (8)

Bligh (9) notes that the profile of the weir itself is open to the objection of being extravagantly bulky, the base having been dredged out so deep as to greatly increase the mean depth of the stone filling. It is quite possible that a row or two of concrete sheet-piles would have been just as effective as the deep breast wall, and would certainly have been much less costly.

The Beswada Weir.

The Beswada Weir lies on pure hard sand of great depth. The downstream apron is faced with large stones, packed on end, and the rock-fill contains stones of all sizes up to 5 and 6 tons.

A row of circular wells of the usual Madras type form the foundation wall. Where the bed was deep in the cold weather channel, it was first filled with sand above the low-water level, and the wells were then built on this bank and undersunk in the dry, the current having been diverted elsewhere. (10)

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(8) See reference #3, p. 175.

(9) See reference #2, pp. 191-192.

(10) See reference #2, p. 199.

Extensive rubble spurs had to be run out and maintained up-stream in order to guide the current straight on to the weir. These expensive training works would probably have been unnecessary if collapsible shutters had been adopted on this structure. (11)

This weir obstructs from 3/7 to ½ of the former waterway of the river at the site where it is built, and although the action on the weir is consequently great, very few repairs have been needed since the work was first completed in 1855. Some stone has been added year by year, and on one occasion a short length of the body wall was torn away. The yearly repairs have averaged about 1½ percent of the original cost. (12)

The Brahmini Weir.

Very little data on the Brahmini Weir are available. A section of the structure is shown in Figure 1, while Table 1 gives a comparison with other weirs.

ROCK-FILL WEIRS---PAVED SURFACE.

The cross-section of this type weir (see Figure 2.) is very similar to that having the rubble facing, but the downstream apron has a paved floor on the surface of the rock-filled slope. In some cases, the facing of the downstream slope as shown by Figure 2 does not appear to be paved, but the stone pitching or rubble is extremely tightly placed. For this reason, most engineers have placed these structures under the classification of paved surface rock-fill weirs.

The Jobra Weir.

The Jobra Weir rests on clay and coarse sand. The rock-filled slope of the weir is made up of 2 to 2½ cu. ft. stones, and is faced with large rubble, solidly packed.

A breach occurred in the center of the weir in 1886, at the site of the center sluices; about half of the center sluices were carried away, besides a portion of the weir, and a deep hole was scoured out on the line of the weir and below it. The cause of the failure was never satisfactorily explained, but it is supposed that leakage occurred below the floor of the under-sluices between the wells in its foundation, and that a stream was created below the floor which gradually undermined it. When a strain was thrown on the floor, it collapsed, and a breach 300 to 400 feet in length was scoured out by the current. The repairs of this failure, which took two years to complete thoroughly, cost about 250,000 Rupees. (13)

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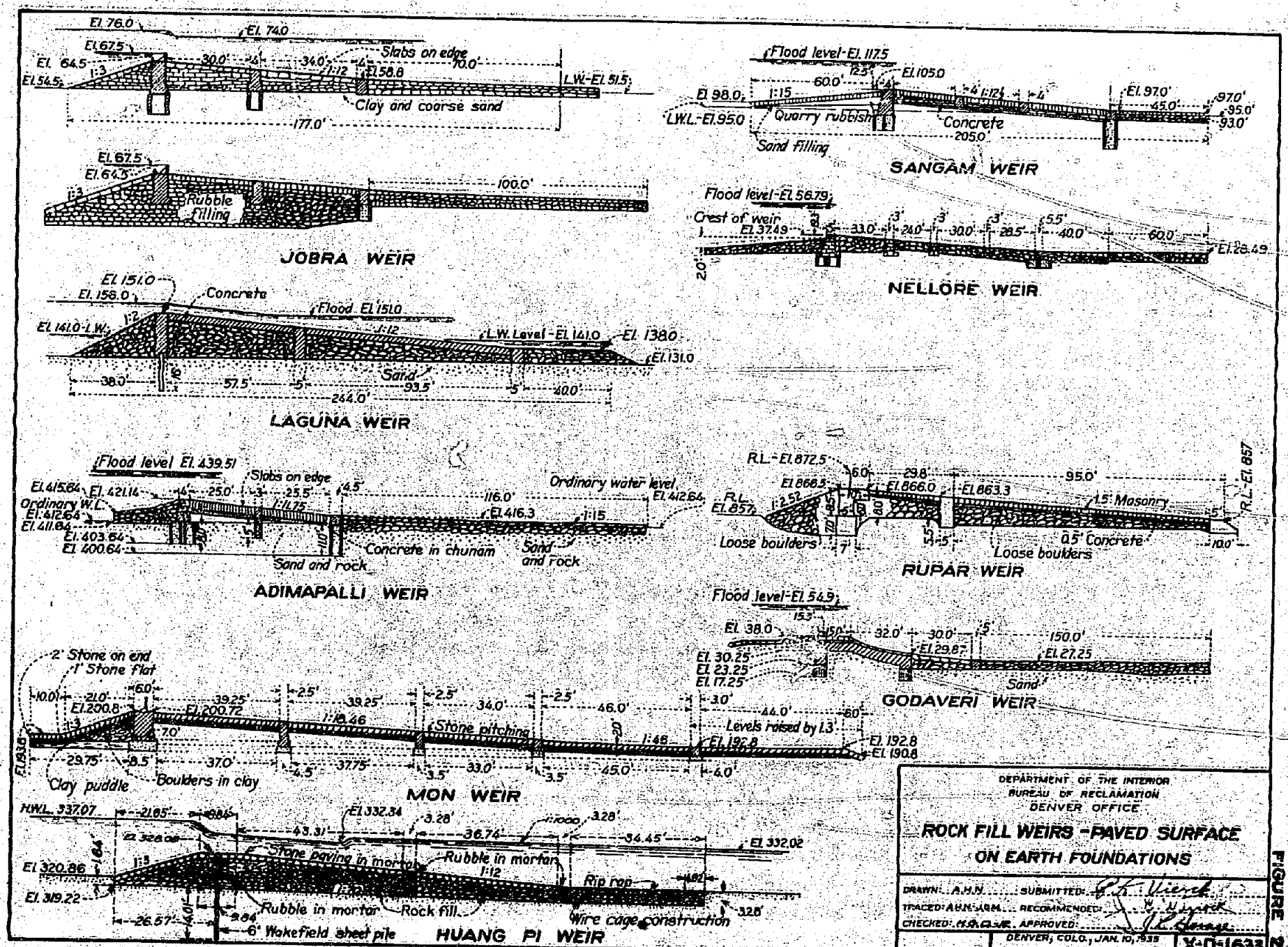
(11) See reference #2, p. 204.

(12) See reference #3, pp. 146-147.

(13) See reference #3, pp. 140-144.



JOBRA WEIR
Rubble filling
Clay and coarse sand
Slabs on edge
LAGUNA WEIR
Concrete
Flood El. 151.0
L.W. Level - El. 141.0
Sand
ADIMAPALLI WEIR
Flood level El. 439.51
Slabs on edge
Ordinary water level
Ordinary W.L.
Concrete in chunam
Sand and rock
SANGAM WEIR
Flood level - El. 117.5
Quarry rubbish
Sand filling
Concrete
NELLORE WEIR
Flood level - El. 56.79
Crest of weir
RUPAR WEIR
Loose boulders
1.5' Masonry
0.5' Concrete
GODAVERI WEIR
Flood level - El. 54.9
Sand
MON WEIR
2' Stone on end
1' Stone flat
Stone pitching
Levels raised by 1.3'
Clay puddle
Boulders in clay
HUANG PI WEIR
Stone paving in mortar
Rubble in mortar
Rip rap
Rock fill
Wire cage construction
6' Wakefield sheet pile
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DENVER OFFICE
ROCK FILL WEIRS - PAVED SURFACE
ON EARTH FOUNDATIONS
DRAWN: A.H.N.
SUBMITTED:
TRACED: A.H.N.-A.G.M.
RECOMMENDED:
CHECKED:
APPROVED:
DENVER, COLO., JAN. 10, 1935
X-D-1633

FIGURE 2.

In constructing the weir, the deep part of the bed was filled up to above low-water level with stone, the line of blocks being omitted here where they might appear to be more desirable. However, Bligh (14) feels that this further demonstrates the absence of necessity in the use of these expensive curtain walls. (Until the Okhla Weir had established a precedent, at least one curtain wall of blocks and wells was considered absolutely necessary, although there was little reason for such belief.)

Bligh (15) states further that the curtain walls under the other portion of the weir could probably have been dispensed with if the upstream apron had been thoroughly stanched and its width increased by 10 to 20 feet, and two more core walls had been added in the fore apron, the spacing being reduced accordingly.

The Adimapalli Weir.

In Bligh's (16) opinion, the expensive well foundations of the Adimapalli weir could have been dispensed with and one or two rows of sheet piles used instead, but these and other modern substitutes were unknown at the time these works were built.

The heavy unit flood discharge of 1.4 second feet necessitates a wide talus.

The Rupar Weir.

The Rupar Weir rests on a bed composed of sand with shingle and boulders of moderate size lying beneath. The weir inclines up-stream from the sluices at an angle of 15 degrees. (17)

The Godaveri Weir.

This is a somewhat special type of weir, being very similar to other structures of this class in having a paved downstream apron surface, but in this case the apron has the form of a concave curve rather than being straight. The original idea for the weir contemplated a vertical drop wall with an ashlar floor below, but this design was abandoned, in favor of that having the curved apron, due to the difficulty of obtaining skilled workmen to execute it. (18)

The four sections of the weir are quite similar. For the first section, the body between the two rows of wells rests

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(14) See reference #2, p. 199.

(15) See reference #2, p. 190.

(16) See reference #2, p. 184.

(17) See reference #3, pp. 154-156.

(18) See reference #3, p. 147.

on a core of sand which was thrown into place, wetted, and rammed. Bligh (19) states that this arrangement is at once economical, and with this coarse sand, quite safe. The practice of making up with sand filling is quite common in Madras' works, and might well be followed with advantage in many cases where rock-filling has been used.

The second section of the weir is very similar to the first with the exception that the downstream wall is founded on a mass of rough stone which extends under the place occupied by the sand in the first section.

The third and fourth sections are generally similar to the first one, but the fourth section is rather stronger---the masonry is a few inches thicker, and the downstream slope is protected by a rough stone apron about 6 or 7 feet wide, which is carried along its entire length. (20)

Bligh (21) feels that these sections contain certain weak points. The expensive masonry apron is quite equal in sectional area to that necessary for a floor of a direct overfall-type weir, while the contour of the profile tends to increase the erosive action on the talus.

The weir has only been maintained by a yearly expenditure of large volumes of rough stone----the records, which are known to be incomplete, indicate that at least 290,000 cu. yds. were expended during the first 20 years of the weir's existence. In Parker's (22) opinion, the reason for this comparative failure is that the concave curve directs the overflowing water against the talus, and the damage is probably caused not so much by the actual transport of the stone down the river as by burying it in deep holes which are excavated by the water and afterwards covered with sand.

The Mon, Sangam, and Nellore Weirs.

Extensive data on these weirs are not available. Figure 2 shows sections of these weirs, while a comparison with other weirs is given in Table 1.

The Huang Pi Weir.

The Huang Pi weir, which is a part of the head-works of the Hu Tuo Ho irrigation system located at Huang Pi, China, is the most recent work of its type to be completed, the construction having been finished in late 1934.

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(19) See reference #2, p. 197.

(20) See reference #3, pp. 147-148.

(21) See reference #2, p. 197-198.

(22) See reference #6, p. 675.

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(19) See reference #2, p. 197.

(20) See reference #3, pp. 147-148.

(21) See reference #2, p. 197-198.

(22) See reference #6, p. 675.

The weir, which is 1424 feet long, is of the rock-fill type with a paved downstream surface. This type was selected for the following reasons: (a) the river bed is filled with deep sand and gravel and it would have cost considerable to reach a solid foundation; (b) rock was available at a very reasonable price while the cost of cement would have made concrete construction uneconomical, and (c) with the rock-fill construction, the preparation of the foundation was more simple. It was also thought that maintenance would be easy and cheap.

The height of the weir was determined by the elevation of the lowest cultivated land upstream, the elevation of which is about 331.36. The crest of the dam was fixed at 328.08 (plus 0.66 feet for settlement) so that for average floods these low farming lands will not be inundated, and at higher floods these lands will be overflowed naturally.

Protection of the weir at the toe is made by several rows of wire cages filled with stone. These cages are 5.58' by 4.92' x 3.28' with 7.87" x 7.87" mesh, the wire being No. 10 galvanized. This form of protection should reduce the maintenance expense on the talus considerably compared to that for the ordinary loose rock-fill type talus.

The upstream slope or heel is not protected except at special points. The Hu Tuo Ho carries a great amount of silt in flood times and the sudden flattening of the slope of the weir will probably deposit considerable silt above the dam, thus forming a protection for the dam proper. The development of cross currents along the heel of the weir can be prevented by careful operation of the sluices, but further protection may be required later at points where the currents occur.

The rock used in the fill averaged 1 ton in weight, and had a minimum size of 7 cu. ft.

The cost of construction was Chinese $126,090.

Although flood records on the Hu Tuo Ho are rather short and unreliable, indications are that the maximum flood is around 140,000 c.f.s. As the structure is very new, data giving flood heads, and flood discharges over the weir are not available. However, a discharge of 140,000 c.f.s. may be assumed as a fair measure of the maximum flood discharge. This gives a unit flood discharge of 98.3 c.f.s. which is within reason. If the flood-drop, or afflux, is assumed to be 3 feet this gives an energy dissipation of 33.5 horse-power per lineal foot of crest. However, this is a very rough assumption and should be considered with caution. (23)

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(23) See reference #12, pp. 1-13.

The Laguna Weir.

The Laguna Weir, or dam, on the Colorado River, 12 miles above Yuma, Arizona, is the only one of this type in the United States. The river has all the attributes of the deltaic rivers of India or Egypt, the main difference being its low flood level and comparatively small discharge which dwindles to almost nothing in the dry season.

The crest of this weir is placed at high flood level (designed elev. 151.0), and consequently blocks the whole of the water section, which is quite unique. The crest wall rests upon a row of 6 inch sheet-piling from 12 to 32 feet in length, which is incorporated in its base to cut off seepage. This piling is made up of three 12 inch planks nailed together in tongue and groove fashion and sharpened at the end.

Considerable sheet-piling was also placed under the middle core-wall because of excessive seepage, and some piling was put under the lower wall, but this latter provision was to supply a foundation over soft bottom.

The top of the middle wall is at elevation 146.0, while that of the lower wall is at elevation 136.0, or 3 feet below what was low-water level when the dam was designed. The space between these three walls is filled with broken stone and capped, except over a small portion, with concrete pavement 18 inches thick. That portion not paved with concrete is faced with rough stone varying in thickness from 2 to 3½ feet. This latter work was originally intended for the entire weir, but later was abandoned because suitable rock for the purpose was not obtainable from the quarries.

The 18 inch concrete paving contains a system of weep-holes; these holes are in the form of slots 3 inches wide and of two different lengths, 7 and 10 feet. These are arranged in longitudinal and transverse rows, the rows being spaced 10 feet apart in one direction and 15 feet apart in the other. The top surface of the concrete was roughened by inserting pieces of rock in the green concrete, their points projecting about 6 inches above the prescribed surface of the paving.

Vincent (24) is of the opinion that neither the above type of weep-hole nor the rock projections are a good practice on a river of this character. The former develop into lines of weakness and wear, and the latter not only may develop pot-holes in the pavement, but they act as obstacles on which the drift has a tendency to collect.

The talus, composed of derrick-sized rock, is 7 feet in

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(24) See reference #11, p. 14.

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depth. As originally built, it extended 40 feet beyond the lower wall. In and adjacent to the old river-bed section, the talus was 50 feet wide and was reinforced by quarry-run beyond the toe.

On the upstream side of the weir, the crest wall is protected by quarry run rock, the fills varying in width on top from 10 to 40 feet.

The crest of the structure is approximately 4800 feet long. The minimum width of the weir on the top is 215 feet; its ordinary height at the crest wall is 10 feet, but in the old river section the rock-fill extends to a depth of 40 feet.

The entire structure rests on sand and silt. Table 2 gives a sieve analysis of the river-bed material taken at and near to the Imperial Dam site. The bed material at the Laguna Weir (which is less than 5 miles downstream from the Imperial) is undoubtedly very similar. This material was dredged to an average depth of 12 feet to accommodate the weir, which was constructed with two-thirds of its bulk under ordinary low-water level.

The sluiceways (one at each end of the weir) are built through the native rock. These sluiceways served as the quarries which furnished the rock used in the construction of the weir. However, the rock formation here was poor, being badly seamed and checked.

The aggregate used in the concrete was made from rock obtained at the quarries. The sand found locally was extremely fine and was supplemented by crushing granite to supply coarser particles. The concrete proportion for the core-walls and paving was 1:3:7.

Inspection of the weir in late November 1909 showed certain minor breaches that had resulted since the completion of the structure the previous March. Slight scour holes had occurred on the concrete face where 150 feet of it had settled about 4 inches next to the crest wall. On the upper side of the crest wall in the old river section, the overpour had carried away the filling down to a depth of 3 to 7 feet, covering a distance of 350 feet. The talus which then stood 3 foot above the water of the pool below, due to a lowering of the bed level, was undisturbed except in two places where parallel currents, caused by obstructions at the old river banks, had cut the fill back from 8 to 10 feet. In places, the deposits of the spoil that had formerly covered the pavement had raised the elevation of the talus 12 to 18 inches.

TABLE 2

SIEVE ANALYSIS OF BED MATERIAL
COLORADO RIVER

RIVER MILE	DEPTH OF SAMPLE ft.	PER CENT PASSING SCREEN								
		SCREEN SIZE IN MM.	25	10.0	2.0	0.59	0.295	0.145	0.074	0.044
660	Surface		100	100	100	100	98.5	90.0	51.0	27.8
657.8	10		100	100	99.5	98.0	63.0	19.0	6.0	----
657.8	20		100	99.5	97.5	93.5	74.0	37.5	3.8	----
657.8	30		100	98.0	90.5	82.0	49.0	28.5	6.3	----

Note:-- Imperial Dam site is at mile 657.8; Laguna Dam is at mile 662.4.

Relative to this first inspection of the structure, Vincent (25) states that in his opinion the most serious feature noted at that time was the immense amount of drift that had accumulated on the surface of the weir especially along the line of the crest wall. For a considerable portion, the drift was almost continuous and had nearly cut off the flow covering that part of the crest. In places this drift was three feet higher than the crest wall, and the logs and brush were mixed with the sand and sediment of the river.

Some time since then it was found that the curved wing-wall on the California side caused a concentration of flow below the weir at this point which resulted in considerable erosion here. To overcome this, the crest was raised along this portion in order to reduce the flow here with respect to that below the remainder of the weir.

In discussing the Laguna weir, Bligh ((26) makes several criticisms and recommendations. In his opinion, a downstream slope of 1 in 15 would be more in accordance with the hydraulic gradient, and would also make the structure heavier. The breast and body walls need not have been carried down to a deep bed level. The rock-filling in the deep channel would silt up immediately and form a mass of natural uncemented concrete of very solid description. The body walls are not sufficiently close to each other to be properly effective. The deep channel, rather than being filled with rock as it was, could have been filled with nothing but sand kept in place by a heap of rubble deposited above and below it.

The weir was designed to hold the water up 10 feet. During construction, a retrogression of the bed level downstream of about 7 feet took place due to the settling out of the solids load above the weir. The flood of June 1909, as shown on Table 3, had a discharge of 150,000 second feet, and the energy dissipation was probably about 29.4 horsepower per lineal foot, assuming that the entire crest was effective. As part of the crest is sometimes blocked by islands, a column is included in Table 2 giving the energy dissipation if two-thirds, or 3200 feet, instead of the full length is effective. As more and more of the solids load came over the crest, the bed gradually rose until in 1920 it had reached about the level which existed before the construction of the weir. During the flood of that year, a cutoff occurred downstream which shortened the river six miles and lowered the water level approximately 7 feet. Although the peak of the 1920 flood had a discharge of 190,000

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(25) See reference #11, pp. 31-32.

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(26) See reference #2, pp. 200-201.

TABLE 3

CONDITIONS AT LAGUNA WEIR IN FLOODS

Date	Upper gage elev. ft.	Lower gage elev. ft.	Drop ft.	Discharge c.f.s.	Using full crest length of 4800 ft.		Using 2/3 of crest length or 3200 ft.	
					Unit discharge c.f.s.	Energy dissipated in h.p. per lineal ft. of crest	Unit discharge c.f.s.	Energy dissipated in h.p. per lineal ft. of crest
June 25, 1909	154.9	146.6	8.3	150,000	31.2	29.4	46.9	44.2
June 22, 1912	155.9	148.9	7.0	144,000	30.0	23.8	45.0	35.8
June 15, 1914	155.7	150.4	5.3	137,000	28.5	17.2	42.8	25.8
July 3, 1917	156.0	151.2	4.8	142,000	29.6	16.1	44.3	24.2
June 9, 1920	156.3	153.3	3.0	190,000	39.6	13.5	59.4	20.2
June 28, 1921	156.7	148.2	8.5	185,000	38.5	37.2	57.8	55.8

second feet, the drop over the crest was only 3.0 feet with an energy dissipation of 13.5 horsepower per lineal foot. The following year, the flood reached 185,000 second feet; the drop had increased to 8.5 feet, and the energy dissipation to 37.2 horsepower per lineal foot. The lowest bed was reached in 1923-24, and about 3 feet of rise has occurred since that time.

The lowering of the tailwater, due to cutoff of the bend, caused severe scour at the lower end of the weir and necessitated extensive repairs, which were made in 1924. The portion of the structure utilized by the river flow (except at flood stages) had contracted to a length of 1500 feet due to the accumulation of debris which had silted in. This length was increased to 2000 feet by removal of the debris. The width of the talus was increased from 45-50 feet to 95 feet. Pavement 12 feet wide and 6 inches thick was laid for 2000 feet along the lower core-wall in an effort to cause the water leaving the weir to flow along the same plane as that of the river and to prevent the tendency to scour holes just off this wall. Repairs were also made below the sluices. The total cost of the repairs made at this time was about $126,000., which is equivalent to a maintenance rate of 0.4 per-cent per year for the 15 year period preceding the flood (the original construction cost being $2,101,374.). Minor maintenance work has been done several times since 1924, although no large floods have occurred in this period. (27) - (28)

Figure 3 shows the present water level within the structure of the weir, this level having been determined from a series of six holes drilled on the downstream face. The tests were made on Jan. 18, 1935 and Feb. 18, 1935, and show the water levels on these dates along with the corresponding headwater and tailwater elevations. Although the exact record has been lost, a similar test made several years ago is known to have shown approximately the same water level as the recent tests show.

SUMMARY

Parker (29) states that his broad experience with several rock-fill weirs leads him to believe that published drawings never properly represent the exact circumstances. The drawings show the initial construction of the weir, and in some cases, where large modifications have been made after construction,

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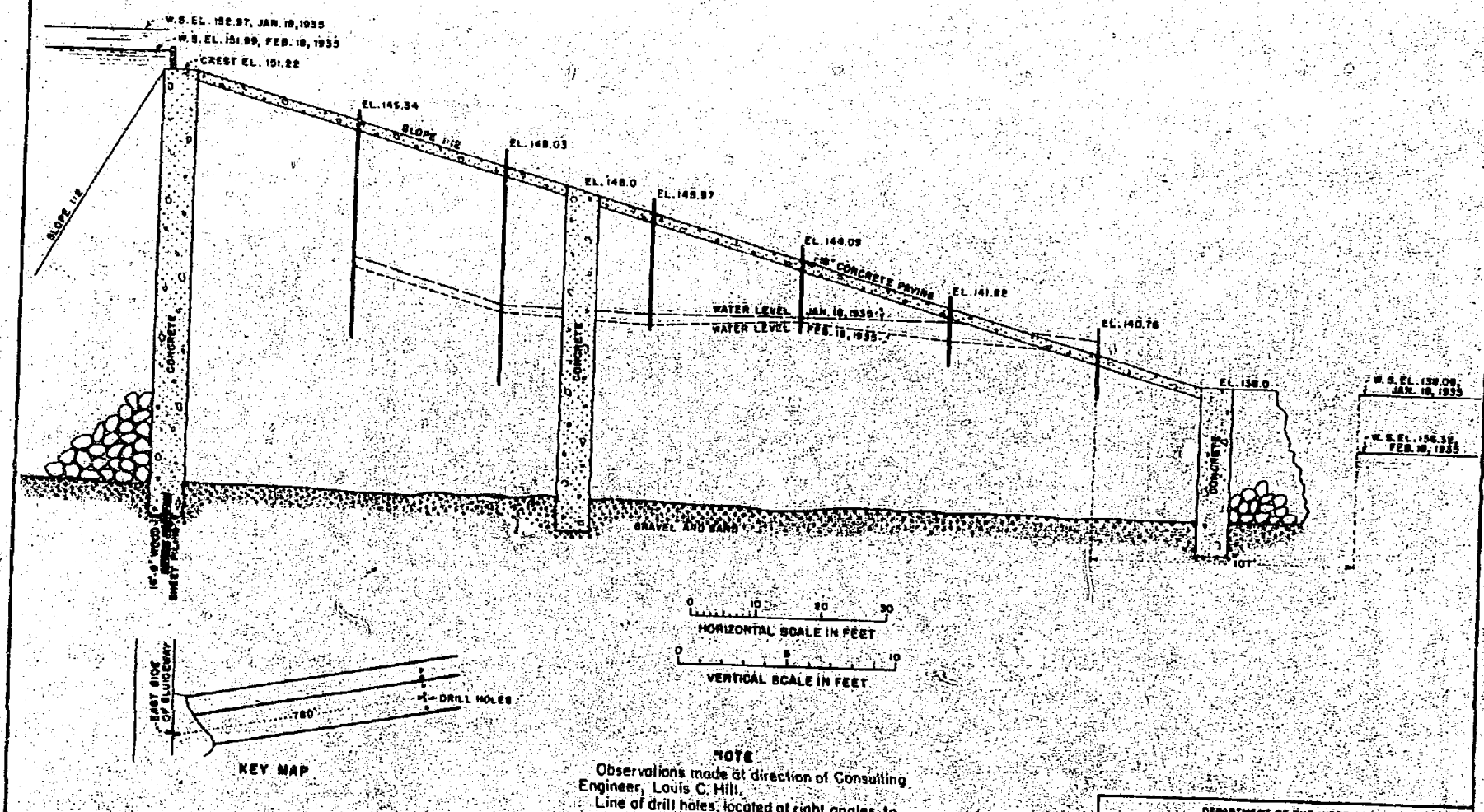
(27) See Tech. Memo. to The Acting Chief Designing Engineer, by E. W. Lane, U. S. Dept. of the Interior, Bur. of Reclamation, Denver, Colo., Jan. 15, 1935.

(28) See also references #8 and 9 in the Bibliography.

(29) See reference #6, pp. 677-678.



KEY MAP

NOTE

Observations made at direction of Consulting Engineer, Louis C. Hill.

Line of drill holes, located at right angles to crest, are 780 ft. from east side of sluiceway. Temporary flash boards, 11 inches high, in place on crest of dam when observations were taken.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DENVER OFFICE

WATER PLANE BENEATH DOWNSTREAM FACE OF LAGUNA WIER

DRAWN R.K.V. SUBMITTED R. F. Vierck
TRACED D.W.S. RECOMMENDED J. G. Hancock
CHECKED H.B.D.-JR. APPROVED J. L. Grace

DENVER, COLO., JUNE 24, 1935 X-D-1684

FIGURE 3

these are more or less accurately recorded. However, large sums are spent annually in repairs and improvements on nearly every structure. These are generally patch-work additions to the aprons and talus and vary from point to point along the weir. Large quantities of stone or concrete blocks are also thrown in every year in order to stop local erosion. In particular, the drawings usually show the talus as a horizontal layer of loose stone or blocks. Any inspection which is conducted under favorable circumstances will generally reveal that a pellmell arrangement of loose stone exists at the tail of a weir, and in some cases, this is really a loose stone facing which slopes down at an angle of 45 degrees and is more or less buried in sand. In an old weir (especially one of the unpaved rubble-faced type), twice the volume of loose stone shown in the drawings is distributed somewhere in the neighborhood of the weir site. The final and permanent structure is probably only arrived at after 20 or even 30 years of careful maintenance.

Buckley (30) lists several factors which affect the safety of the rock-fill type weir. In those cases where the chief danger to a weir is from piping, or underscour, in the permeable bed beneath the weir, the true measure of security of the structure is the distance through the soil which a current of water would travel before it could rise up again (i. e., the length of the path of percolation), and the resultant percolation velocity with respect to the allowable. There are many other factors to consider. The river bed downstream from the weir should be protected from the flow so that the bed will not wash out and undermine the foundation of the weir, and so that the pounding of the water will not bury the rock-fill of the talus. In this connection it is recommended that the weir be so constructed that the hydraulic jump at all stages and discharges will be formed upon the sloping apron far enough up so that the entire length of the jump is over the rubble or paved face of the rock-fill (31). The surface of the weir which is exposed to scour should be of material hard and heavy enough to resist that erosion. It is also true that the structure must have sufficient weight to resist the horizontal pressure of the head it supports, and also to withstand the upward pressure on the base of the foundations which the head produces, including the effect of submergence. In addition, the weir should be protected from parallel currents.

Of the above points to be considered in the design, some can be controlled quite well; others are the source of continual and expensive maintenance. The correctness of the

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(30) See reference #3, p. 175.

(31) See reference #10.

original design will, of course, eliminate some of these weaknesses and reduce all of them somewhat, but such things as the renewal and repair of the weir structure caused by the erosive action of the flow are largely subject to the head and unit discharge which prevail for the particular river and the determined weir height, i. e., the energy to be dissipated per lineal foot of crest. In addition, the wear and the wash of the stone depend on the hardness and the size of stone available.

It is probable that a rock-fill weir is only advisable where the static head is low and the energy to be dissipated per lineal foot of crest is not great. An abundant supply of cheap hard stone available near the site of the structure, and a good source of low-wage unskilled labor are also of primary importance.

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