DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
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REPLY TO
ATTENTION OF

CEWES-CR-S (1110-2-1402b) 31 August 1997

MEMORANDUM FOR Commander, U.S. Army Engineer District, Portland,
ATTN: CENWP-PE-HD, (Mr. Jim Stow), P.O. Box 2946,
Portland, OR 97208-2946

SUBJECT: Data Report, Bonneville Spillway Section Model, Columbia River, OR

1. This is the first data report in a series from experiments conducted on the Bonneville Section Model. Upon completion of all experiments identified by the Portland District, the data reports will be compiled into a final report encompassing the entire study.

2. The Bonneville section model reproduces 400 ft of approach, three 50-ft-wide gate bays, two half bays (25-ft-wide), four 10-ft wide piers, vertical-lift gates, the spillway, the 81-ft-long stilling basin, baffle blocks, endsill, and 600 ft of exit channel (Figure 1). The spillway was fabricated of sheet metal and given a painted finish. The vertical-lift gates and piers were fabricated out of clear plastic (plexiglas). The stilling basin, baffle blocks and endsill were fabricated out of plywood and given a painted finish. The exit channel was molded in concrete and pea gravel to examine any scour that may occur. Topography downstream of gates 2-6 was reproduced.

3. Experiments were conducted to characterize the hydraulic performance of the existing nappe deflectors on gate bays 4-6. Gate bays 2-3 did not have deflectors. The purpose of flow deflectors is to reduce or eliminate plunging flow and the transport of entrained air to the apron invert. Without the spillway deflector, the plunging flow jet conforms to the spillway shape and transports entrained air to the full depth of the stilling basin. While this is an effective means of dissipating energy in the basin, the entrained air is subjected to very high hydrostatic pressures, which is the cause of gas absorption to supersaturated levels. Previous studies have shown that for discharges of 2,600 cfs, 5,000 and 5,900 cfs deflector submergences of 1-7, 7-11 and 10-12 ft respectively the skimming action would occur over a wider range of normal tailwaters and for discharges above 5,900 cfs, no satisfactory flow conditions were observed.[1]

4. Experiments involved evaluating flow conditions over the deflectors for gate openings of 1.0, 2.9, 4.9, 6.8, 8.7, 10.6, 12.6,14.5,16.4,18.3,20.2, and 22.1 ft with a range of tailwaters. The gate opening in the prototype is referred to as a "dog" (as shown in Table 1).

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[1] WES Data Report, John Day Spillway Section Model, Columbia River, OR, 3 June 1996.

Table 1
GATE DOGS FOR BONNEVILLE

GATE OPENINGS DOGS	GATE OPENINGS FT	DISCHARGE PER BAY CFS
1	1.0	3,100
2	2.9	6,700
3	4.9	10,300
4	6.8	13,700
5	8.7	17,200
6	10.6	20,600
7	12.6	24,000
8	14.5	27,300
9	16.4	30,600
10	18.3	33,800
11	20.2	37,000
12	22.1	40,200

Each discharge was set and the upper pool allowed to stabilize at el 74.0, a tailwater el was set and allowed to stabilize, and flow conditions at the deflector were recorded as aerated plunging, oscillating plunging, skimming, undular, or a hydraulic jump. Flow conditions were documented with video and photographs.

a. Aerated plunging flow was observed to occur when a pocket of air formed immediately downstream from the deflector, under the nappe as flow passed over the deflector (Figure 2).

b. Oscillating plunging flow occurred when the venting of the nappe was inconsistent and produced an unstable condition with periods of the flow alternately plunging to the stilling basin floor or attempting to ride the surface of the tailwater (Figure 3).

c. Skimming flow occurred when the tailwater elevation was sufficient to prevent aeration at the downstream edge of the deflector and the flow jet remained along the surface of the tailwater (Figure 4).This condition produces the lowest gas levels in the tailrace.

d. Undular flow occurred at higher tailwater submergences (the differential between tailwater and deflector elevation). The nappe rode up on the downstream water surface forming an undular jump resulting in large standing waves and plunging flows in the vicinity of the baffle blocks (Figure 5).

e. With high tailwater elevations, a hydraulic roller formed at the deflector, and with extremely high tailwater, the nappe submerged, resulting in a submerged hydraulic jump that was elevated off the stilling basin floor by the deflector (Figure 6).

5. Hydraulic performance of the 12.5-ft long deflector (Type 1, Figure 7) at el 14.0, previously developed in 1984 at the Bonneville Hydraulics Laboratory[2], was evaluated for discharges of 3,100, 6,700, 13,700, 20,600, 27,300, 33,800, and 40,200 cfs/bay respectively. The results of experiments with the Type 1 deflector showed the spillway flow jet sprayed off the deflector causing large highly aerated waves to form in the basin during most flow conditions. The turbulence from these waves transported air bubbles to the apron invert because of the plunging nature of the flow induced by the waves. Experiments showed that at very low tailwater elevations, the underside of the nappe would be aerated and the flow would plunge to the stilling basin floor with all discharges that were investigated. This condition entrained large volumes of air and transported air bubbles to the apron invert and tailrace area (aerated plunging flow). With increased tailwater , the venting of the nappe was inconsistent and produced an unstable condition with periods of the flow alternately plunging to the stilling basin floor or tending to ride the surface of the tailwater (oscillating plunging flow). When the tailwater elevation was sufficient to prevent aeration at the downstream edge of the deflector, the jet flowed along the surface and produced a relatively smooth "skimming" action (skimming flow). With higher tailwater submergences, the nappe would ride up on the downstream water surface forming an undulating surface with large standing waves and plunging flows in the vicinity of the baffle blocks (undular flow). With high tailwater elevations, a hydraulic roller (hydraulic jump) would form at the deflector, and with extremely high tailwater, the nappe was submerged, resulting in a submerged hydraulic jump that was elevated off the stilling basin floor by the deflector Data from these experiments is recorded in Table 2.

Table 2
Deflector Submergence Data
original design, deflector at el 14.0

1 dog, 3,100 cfs/bay, HW el 74.0

Submergence ft	Tailwater El	Flow Description
0	14	skimming
1	15	skimming
2	16	skimming
3	17	undular
4	18	undular
5	19	undular
6	20	undular
7	21	undular
8	22	hydraulic jump
9	23	hydraulic jump
10	24	hydraulic jump

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[2] Technical Report no. 104-1, "Spillway Deflectors at Bonneville, John Day and McNary Dams on Columbia River, Oregon-Washington and Ice Harbor, Lower Monumental and Little Goose Dams on Snake River, Washington", September 1984.

Table 2 (continued)
Deflector Submergence Data
original design, deflector at el 14.0

1 dog, 3,100 cfs/bay, HW el 74.0

Submergence ft	Tailwater El	Flow Description
11	25	hydraulic jump
12	26	hydraulic jump
13	27	hydraulic jump

2 dogs, 6,700 cfs/bay, HW el 74.0

Submergence ft	Tailwater El	Flow Description
0	14	aerated plunging
1	15	oscillating plunging
2	16	skimming
3	17	skimming
4	18	skimming
5	19	undular
6	20	undular
7	21	undular
8	22	undular
9	23	undular
10	24	undular
11	25	undular
12	26	undular
13	27	hydraulic jump
14	28	hydraulic jump
15	29	hydraulic jump
16	30	hydraulic jump
17	31	submerged jump

Table 2 (continued)
Deflector Submergence Data
original design, deflector at el 14.0

4 dogs, 13,700 cfs/bay, HW el 74.0

Submergence ft	Tailwater El	Flow Description
0	14	aerated plunging
1	15	aerated plunging
2	16	oscillating plunging
3	17	oscillating plunging
4	18	plunging
5	19	plunging
6	20	plunging
7	21	plunging
8	22	plunging
9	23	plunging
10	24	plunging
11	25	plunging
12	26	undular
13	27	undular
14	28	undular
15	29	undular
16	30	undular
17	31	undular
18	32	undular
19	33	undular
20	34	undular
21	35	hydraulic jump

Table 2 (continued) Deflector Submergence Data original design, deflector at el 14.0		
6 dogs, 20,600 cfs/bay, HW el 74.0		
Submergence ft	Tailwater El	Flow Description
0	14	aerated plunging
1	15	aerated plunging
2	16	aerated plunging
3	17	aerated plunging
4	18	oscillating plunging
5	19	oscillating plunging
6	20	plunging
7	21	plunging
8	22	plunging
9	23	plunging
10	24	plunging
11	25	plunging
12	26	plunging
13	27	plunging
14	28	plunging
15	29	undular
16	30	undular
17	31	undular
18	32	undular
19	33	undular
20	34	undular
21	35	undular
22	36	undular
23	37	undular

Table 2 (continued)
Deflector Submergence Data
original design, deflector a el 14.0

Submergence ft	Tailwater El	Flow Description
6 dogs, 20,600 cfs/bay, HW el 74.0 (concluded)		
24	38	undular
25	39	hydraulic jump
26	40	hydraulic jump
27	41	hydraulic jump
28	42	hydraulic jump
29	43	hydraulic jump
30	44	hydraulic jump
31	45	hydraulic jump
8 dogs, 27,300 cfs/bay, HW el 74.0		
0	14	oscillating plunging
1	15	oscillating plunging
2	16	oscillating plunging
3	17	oscillating plunging
4	18	oscillating plunging
5	19	oscillating plunging
6	20	oscillating plunging
7	21	plunging
8	22	plunging
9	23	plunging
10	24	plunging
11	25	plunging
12	26	plunging
13	27	plunging
14	28	plunging

Table 2 (continued)
Deflector Submergence Data
original design, deflector at el 14.0

8 dogs, 27,300 cfs/bay, HW el 74.0 (concluded)		
Submergence ft	Tailwater El	Flow Description
15	29	plunging
16	30	plunging
17	31	plunging
18	32	plunging
19	33	undular
20	34	undular
21	35	undular
22	36	undular
23	37	undular
24	38	undular
25	39	undular
26	40	undular
27	41	undular
28	42	undular
29	43	undular
30	44	hydraulic jump
31	45	hydraulic jump
32	46	hydraulic jump
33	47	hydraulic jump
34	48	submerged jump

6. A graphical description of deflector performance as a function of submergence and spillway discharge is shown in Figure 8. Data for the deflector was plotted in terms of submergence (the differential between the

tailwater elevation and the deflector elevation), in ft, versus discharge, in 1,000 cfs/bay for each condition. For discharges above 6,700 cfs/bay, flow over the deflector became considerably turbulent and the skimming capacity of the deflectors became inundated. Flow exiting the deflectored bays (bays 4-6) had higher energy projected further downstream than the non-deflectored bays (bays 2 and 3).

7. If there are any questions or comments please contact Mr. Steve Wilhelms at (601) 634-2475 or Ms. Deborah Cooper at (601) 634-3558.

FOR THE DIRECTOR, COASTAL AND HYDRAULICS LABORATORY:

8 Encls

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Chief
Rivers and Structures Division

CF (w/encl):
CENPD-ET-EN/Mr. Dave Ponganis
CECW-EH-D/Mr. Tom Munsey

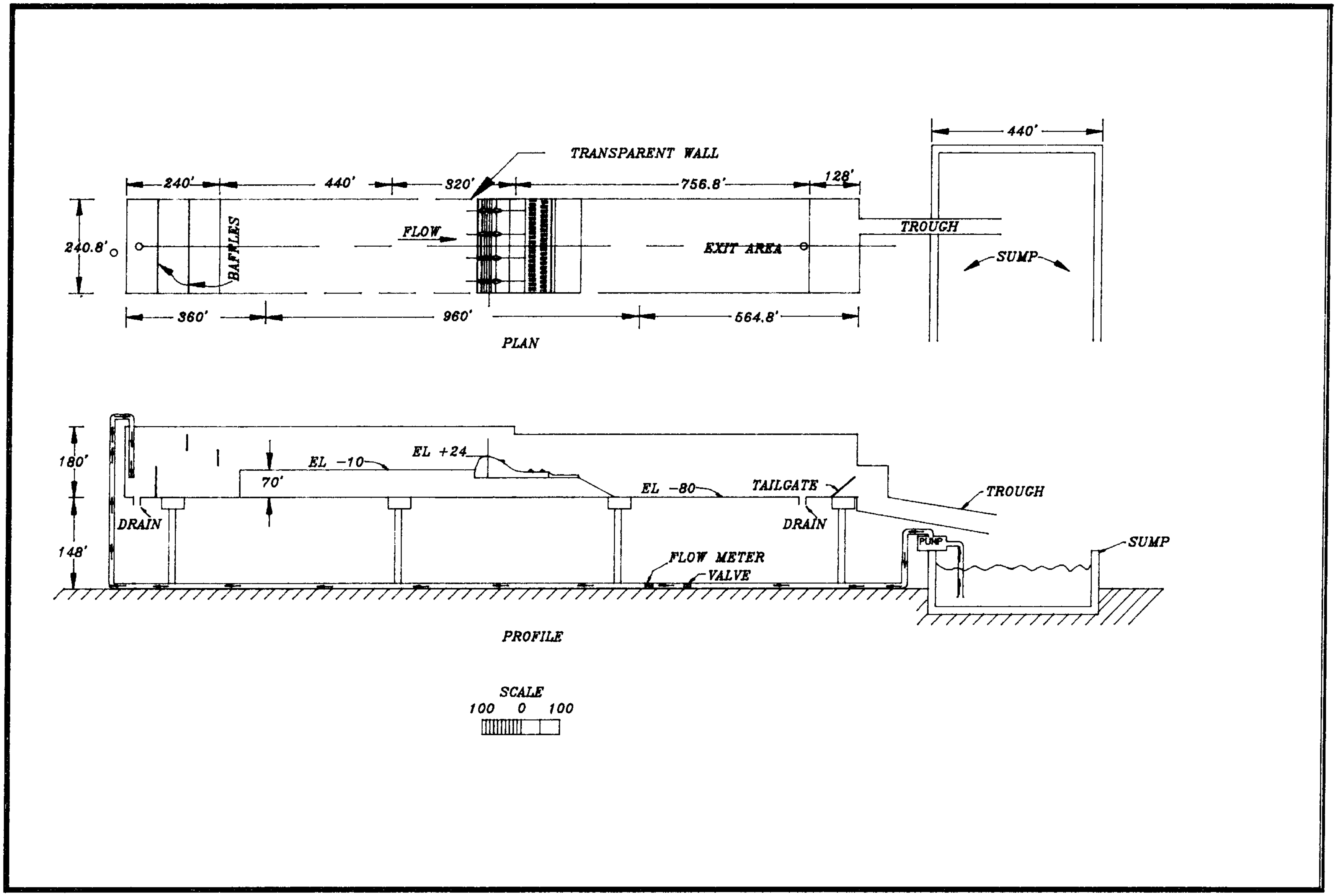


Figure 1. Model Layout

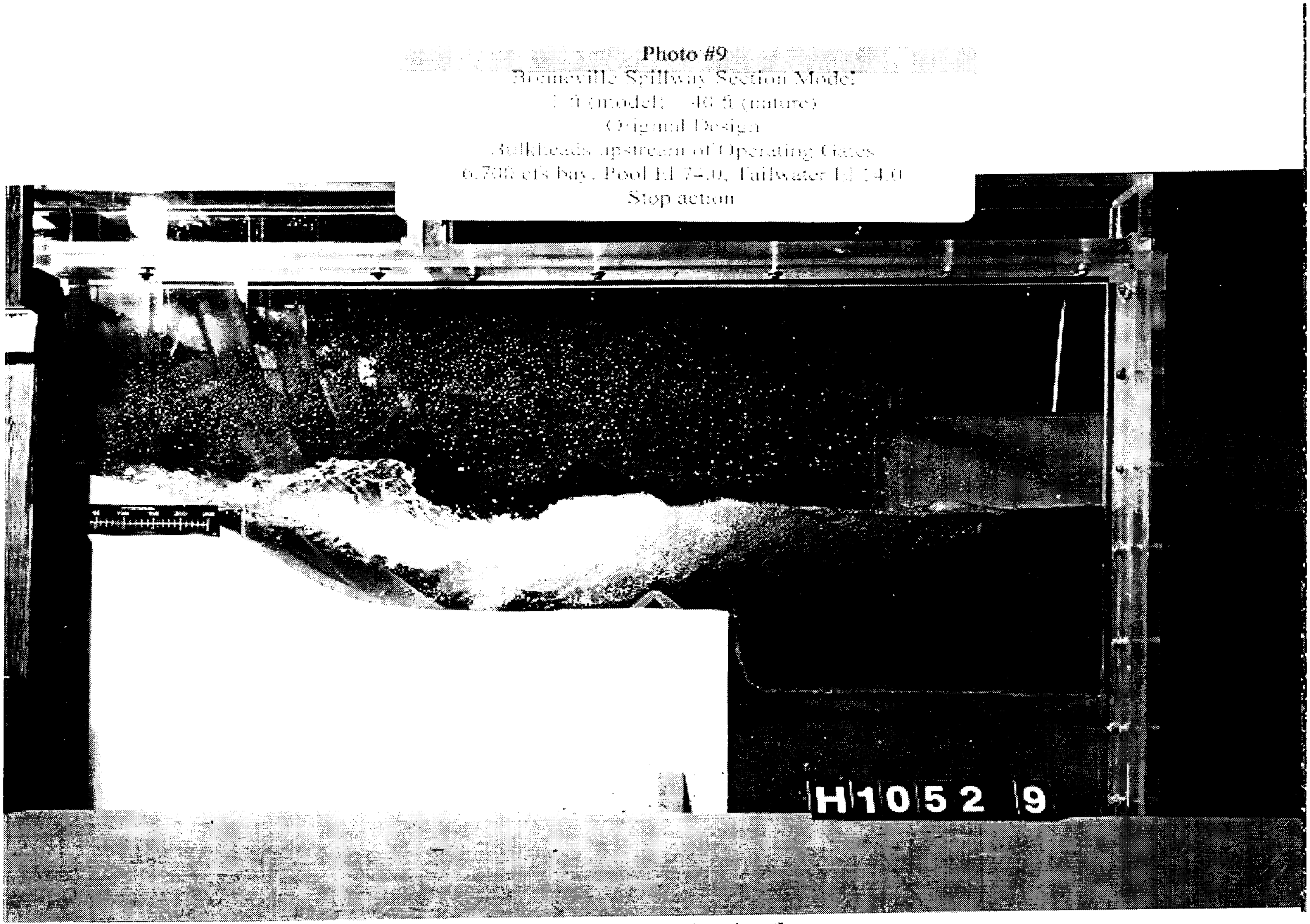


Photo #9
Bonneville Spillway Section Model
1 ft (model) = 40 ft (nature)
Original Design
Bulkheads upstream of Operating Gates
6,700 cfs bay, Pool El 74.0, Tailwater El 14.0
Stop action

Figure 2. Aerated plunging flow

Photo #33
Bonneville Spillway Section Model
1 ft (model) = 40 ft (nature)
Original Design
Without Bulkheads
20,600 cfs/bay
Pool El 74.0, Tailwater El 25.0
Stop Action

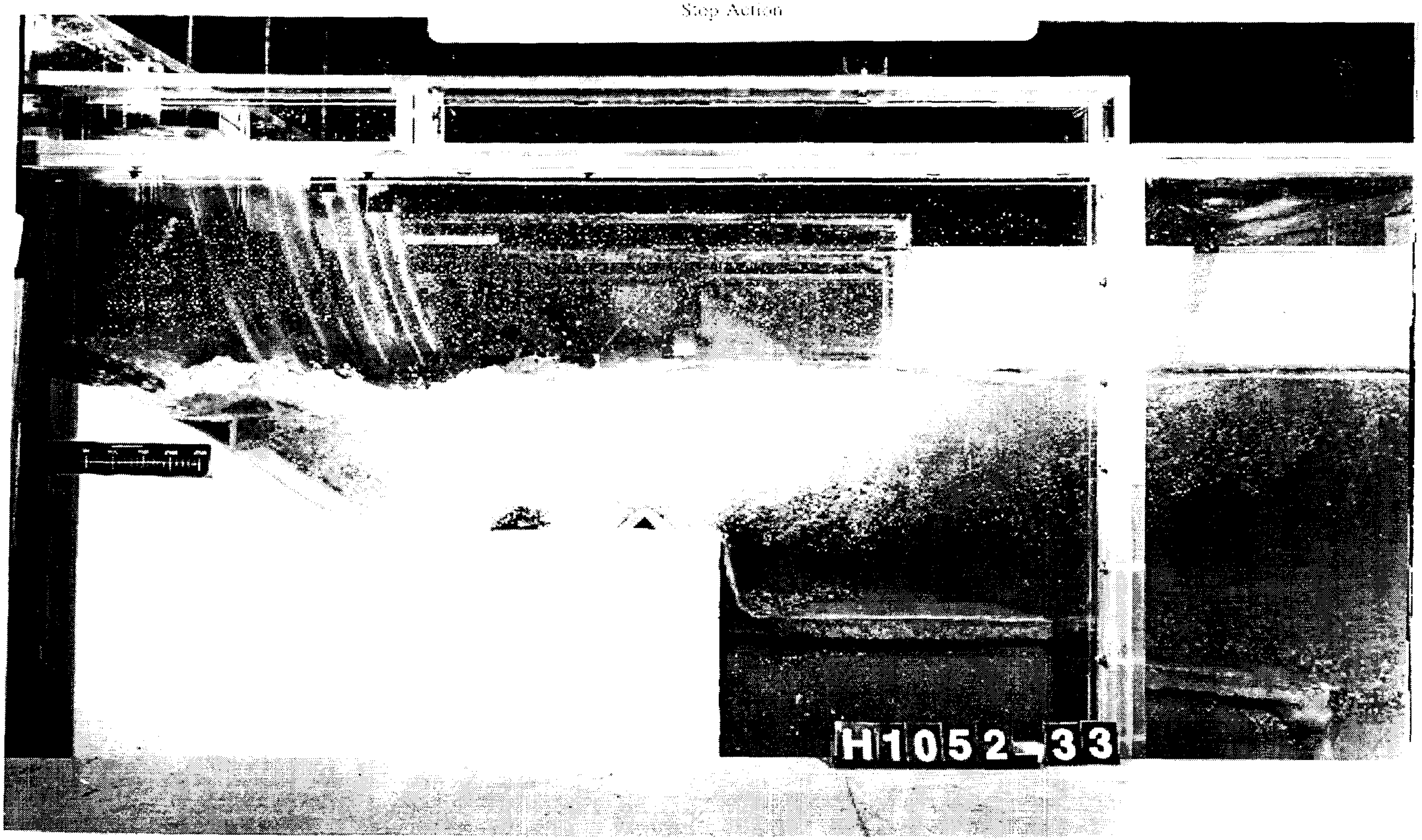


Figure 3. Oscillating plunging flow

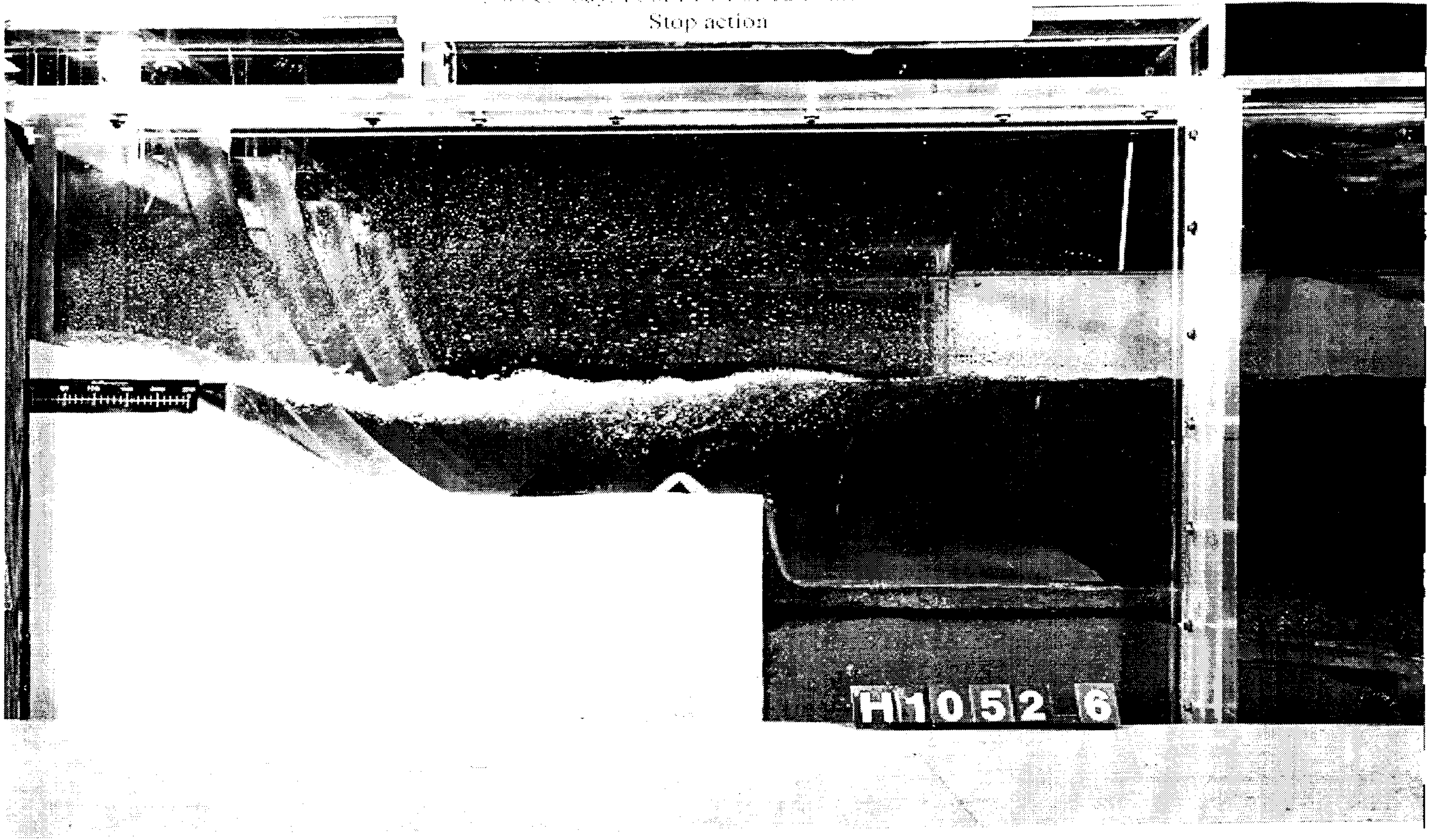


Photo #6
Bonneville Spillway Section Model
1 ft (model) = 40 ft (nature)
Original Design
Bulkheads upstream of Operating Gates
3,100 cfs/bay, Pool El 74.0, Tailwater El 14.0
Stop action

Figure 4. Skimming flow

Photo #31
Bonneville Spillway Section Model
1 ft (model) = 40 ft (nature)
Original Design
Without Bulkheads
13,700 cfs/bay
Pool El 74.0, Tailwater El 27.0
Stop Action

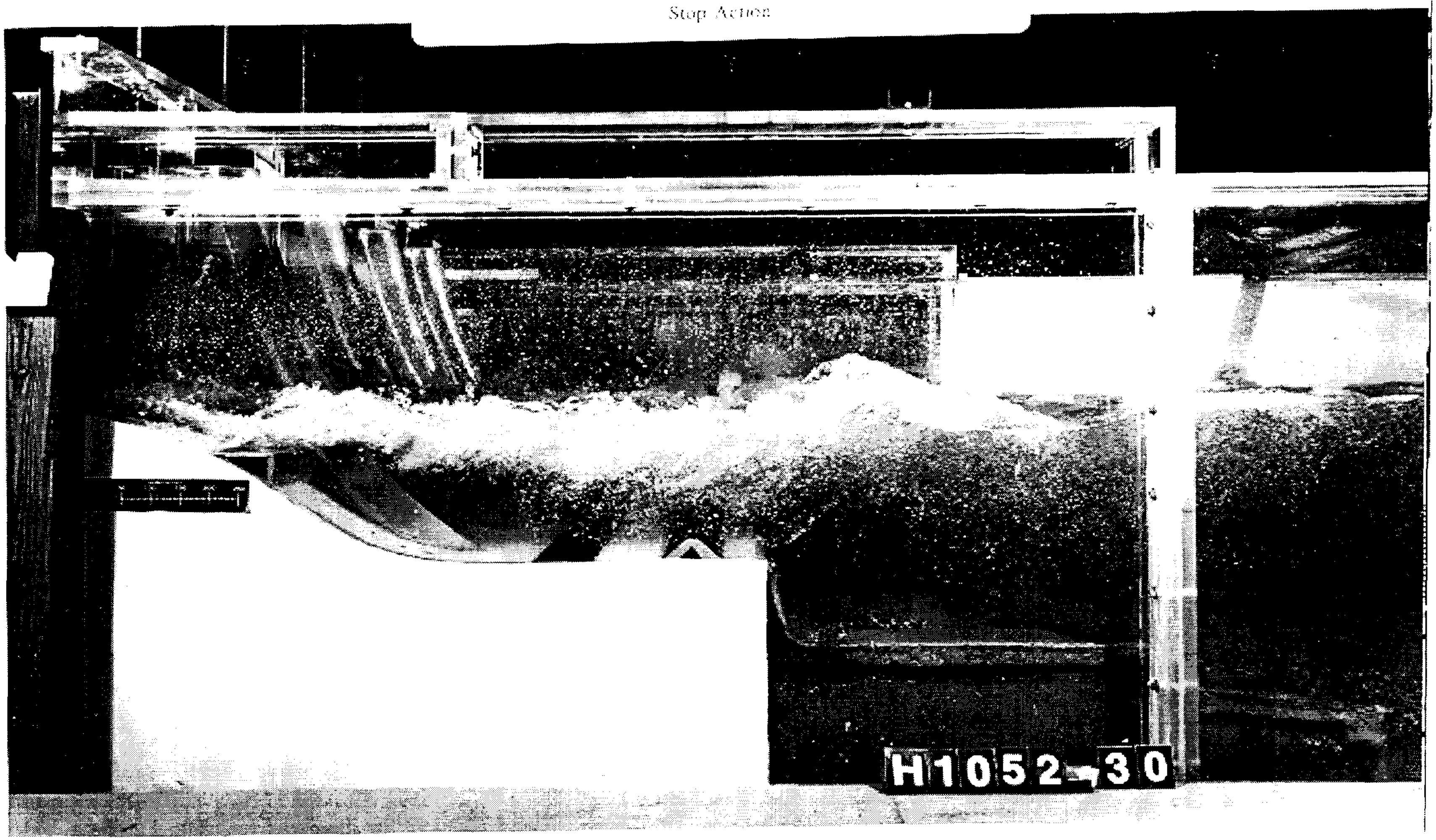


Figure 5. Undular flow

Photo #39
Bonneville Spillway Section Model
1 ft (model) = 40 ft (nature)
Original Design
Without Bulkheads
27,300 cfs/bay
Pool El 74.0 Tailwater El 45.4
Stop Action

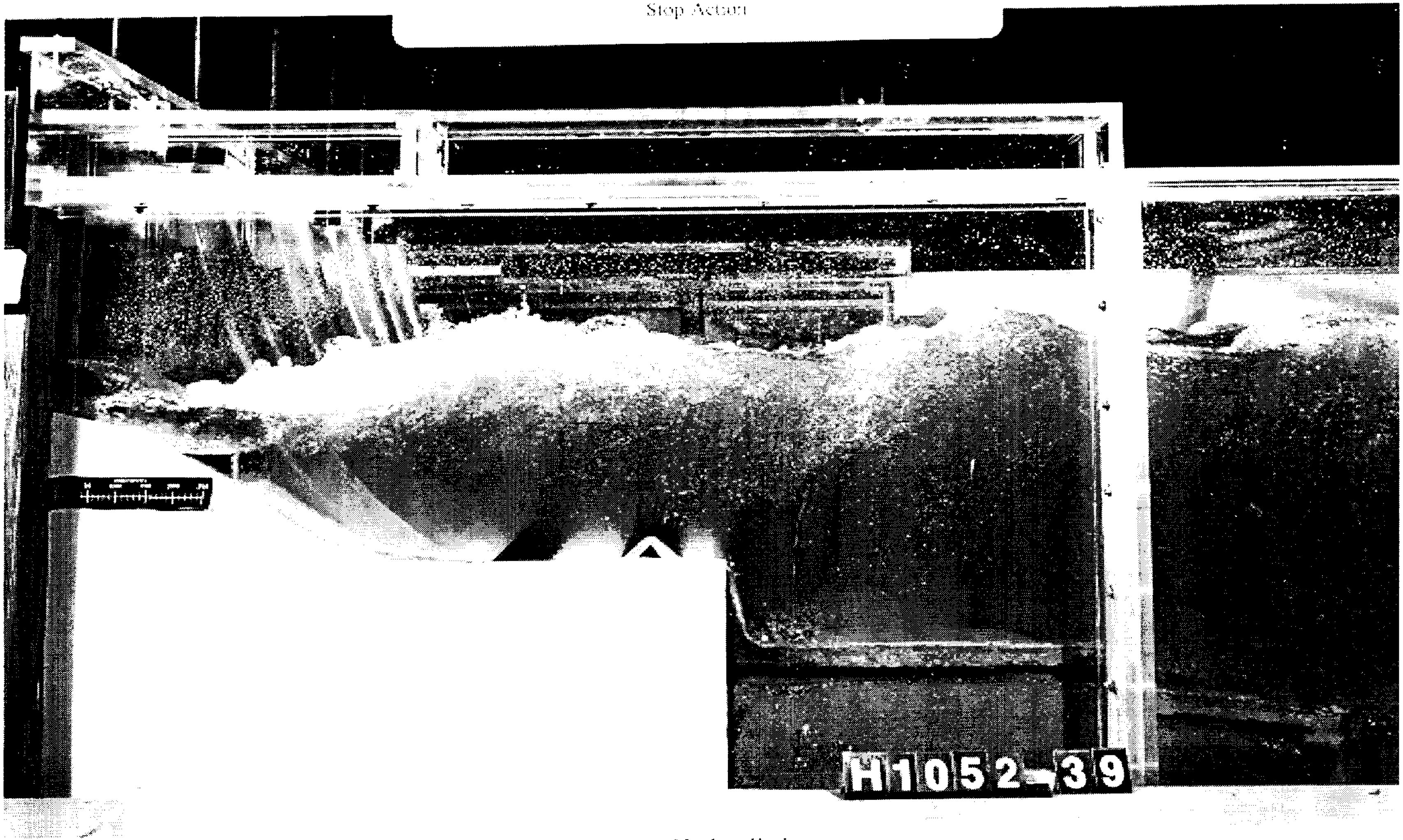


Figure 6. Hydraulic jump

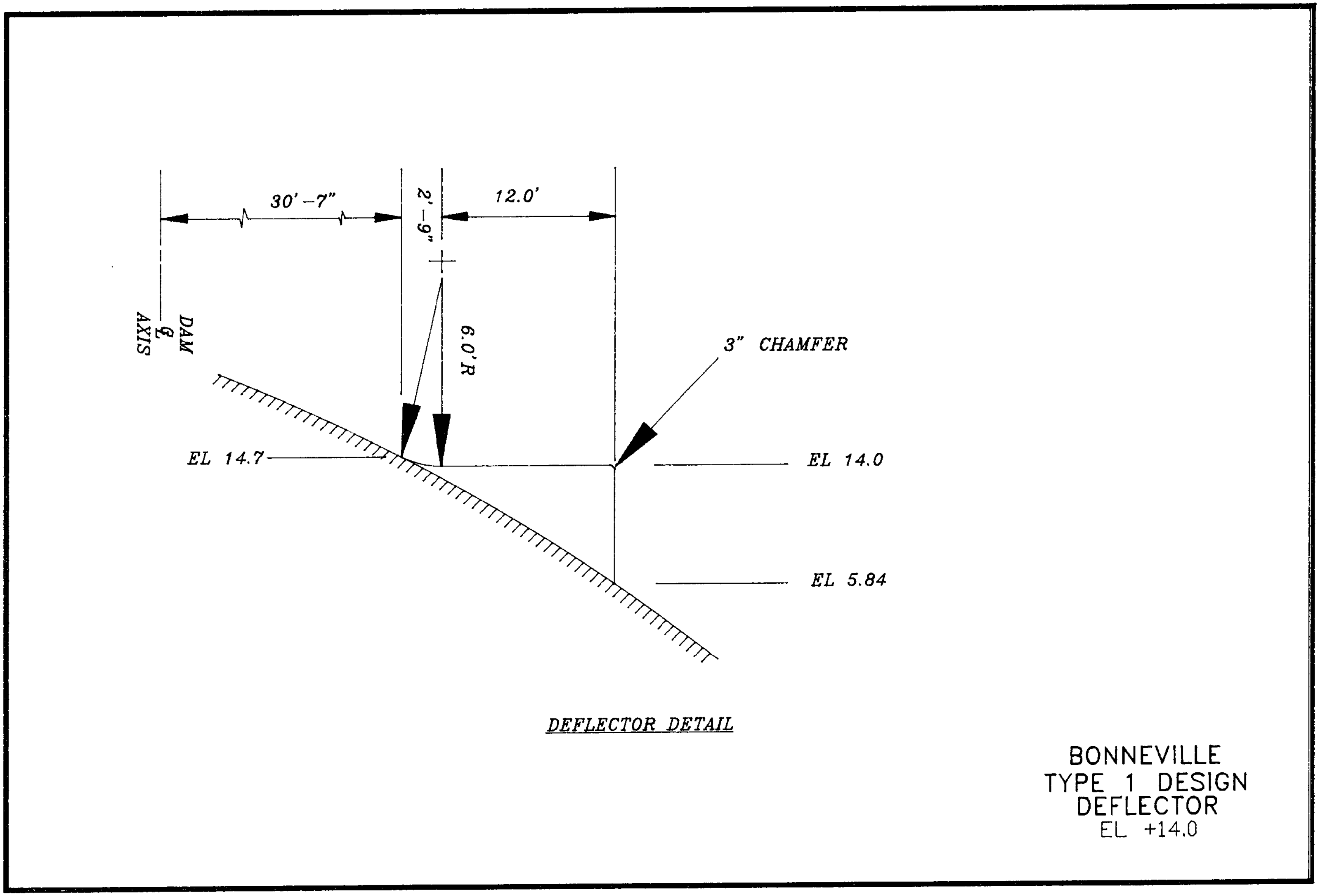
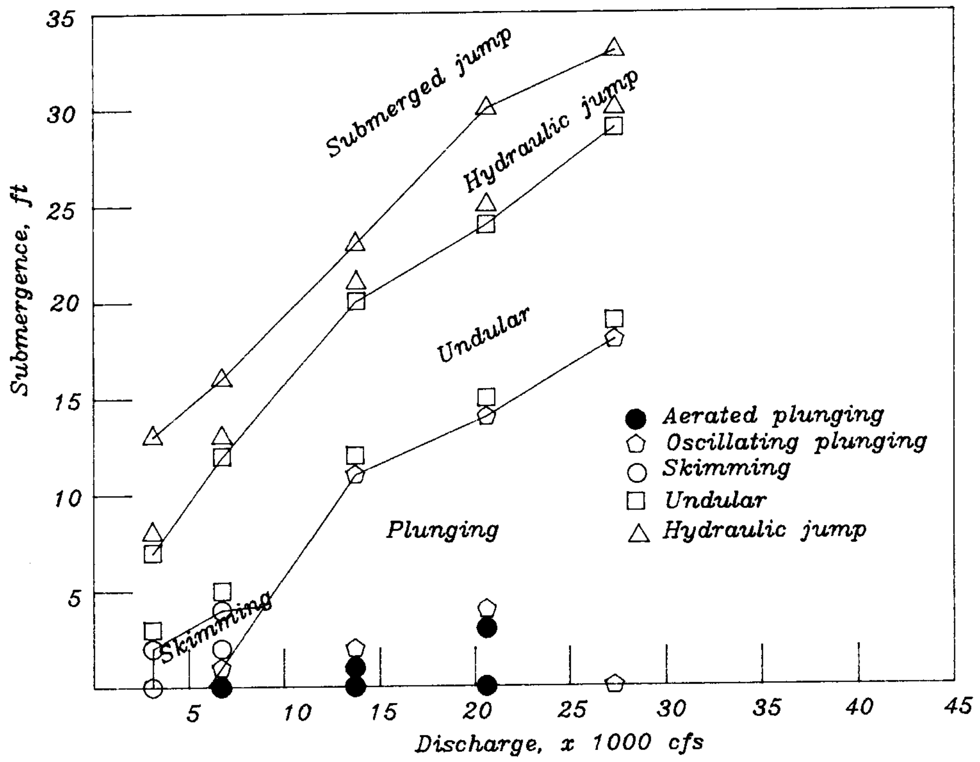


Figure 7. Type 1 Deflector, El +14.0



BONNEVILLE
TYPE 1 FLOW DEFLECTOR
EL 14

Figure 8. Deflector performance curves

Pl.x2

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