HYDRAULIC MODEL
INVESTIGATION

TECHNICAL REPORT NO. 194-1

Emergency Closure System and Flood Control Regulation Gate for Hiram M. Chittenden Locks at Lake Washington Ship Canal

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

A 1:50-scale model was used to evaluate the proposed emergency closure system (ECS) for the large lock at the Lake Washington Ship Canal project. The model was also used to evaluate the acceptability of using the large lock chamber as an auxiliary spillway with the ECS functioning as a regulating gate.

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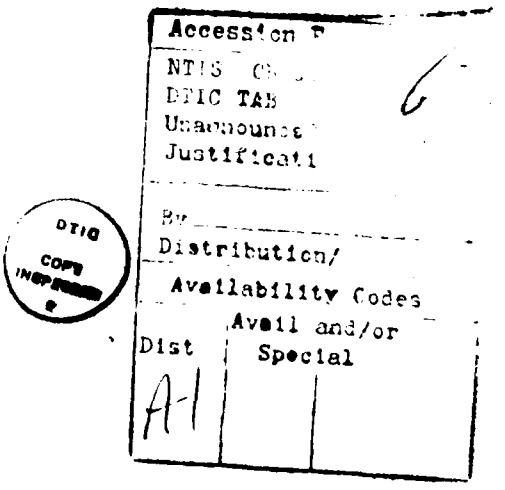
In the emergency closure mode, maximum hydrodynamic downpull forces of 20 Kips were measured on the ECS lowering cables when the bulkheads were stacked one on top of the other (operating plan). Individual bulkheads could not be successfully placed in the flow.

The model showed that the ECS would be acceptable as a regulating gate for the large lock; however, some modifications within the large lock chamber would be required prior to the lock's satisfactory performance as an auxiliary spillway.

PREFACE

Model studies of the Emergency Closure System (ECS) at the Lake Washington Ship Canal and Hiram M. Chittenden Locks project were authorized by North Pacific Division (NPD) on 3 April 1981, at the request of the U.S. Army Corps of Engineers, Seattle District (NPS). Studies were conducted at the Division Hydraulic Laboratory, U.S. Army Engineering Division, North Pacific, during the period May 1981 through April 1982.

The model studies were conducted by Mr. R. L. Johnson under the supervision of Mr. P. M. Smith, Director, of the Laboratory. This report was prepared by Mr. M. M. Kubo, NPS Hydraulics Section.



CONTENTS

CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

MULTIPLY	BY	TO OBTAIN
Feet	0.3048	Meters
Miles	1.6093	Kilometers
Feet per Second	0.3048	Meter per Second
Cubic Feet per Second	0.02832	Cubic Meters per Second
Pounds (Mass)	0.45359	Kilograms

EMERGENCY CLOSURE SYSTEM
AND FLOOD CONTROL REGULATION GATE
FOR HIRAM M. CHITTENDEN LOCKS
AT LAKE WASHINGTON SHIP CANAL

Hydraulic Model Investigations

PART I: INTRODUCTION

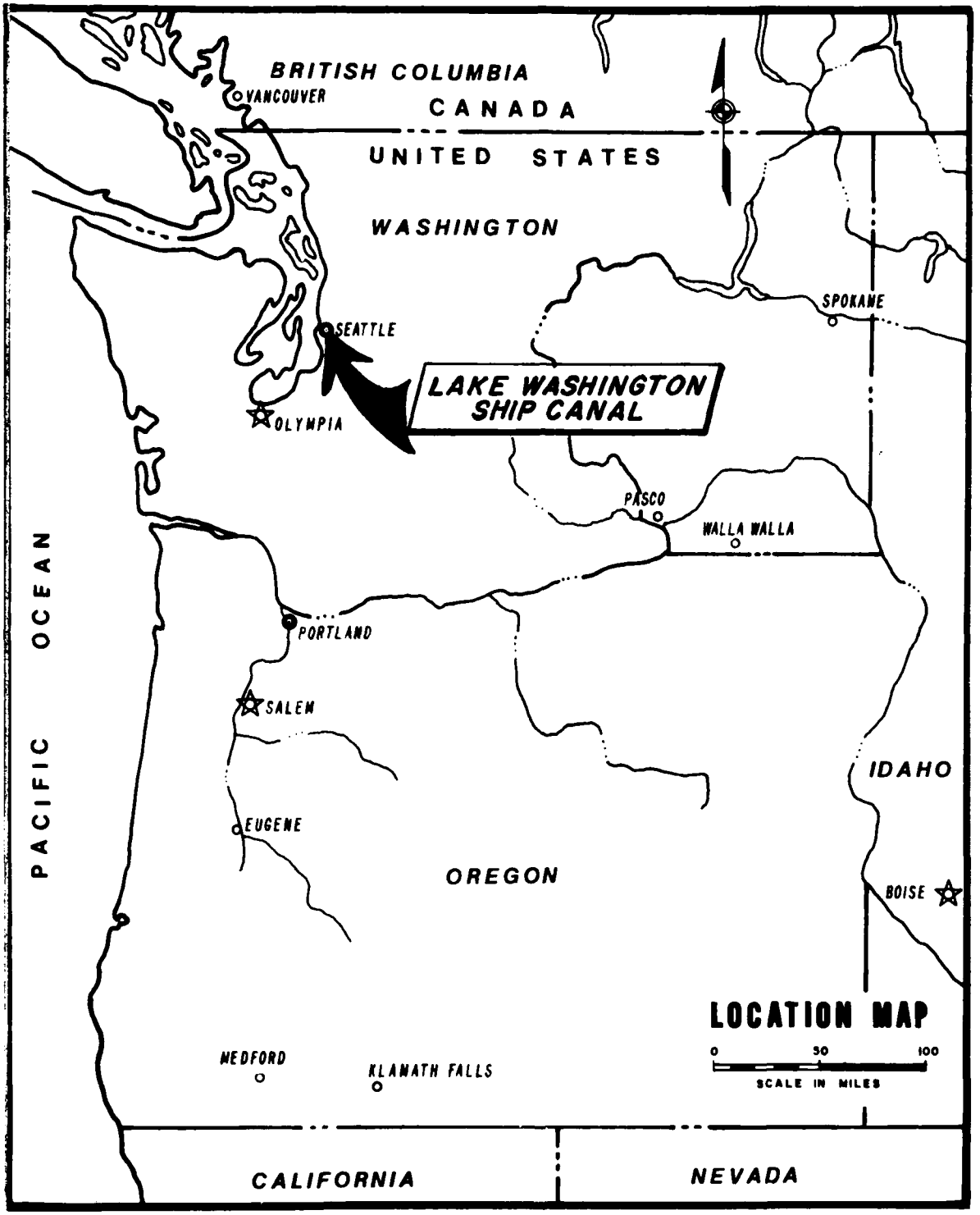
The Prototype

1. Lake Washington Ship Canal (LWSC) and Hiram M. Chittenden Locks, located in Seattle, Washington (figure 1), connects freshwater Lake Washington through Lake Union to saltwater Shilshole Bay and Puget Sound (plate 1). The locks are located at the entrance to Salmon Bay. General arrangement of the project facilities and appurtenant structures are as shown on plate 2.

Design Considerations

2. The proposed emergency closure system (ECS) is to be installed at the entrance to the large lock. The system consists of a series of bulkheads which would be stacked one on top of the other and lowered into the lock chamber by carriages located in slots on the lock walls. During emergency closure conditions, flow would occur only under the bottom bulkhead.

3. Probable maximum flood (PMF) analysis indicates that present project outflow capability is inadequate and additional outflow capability will be required to control Lake Washington to presently accepted levels during passage of floods approaching standard project flood up to PMF magnitude. The use of the large lock chamber as an auxiliary spillway with the ECS functioning as a regulating gate would be considered as a viable alternative for providing additional discharge capacity.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LAKE WASHINGTON SHIP CANAL
OLYMPIA
PASCO
WALLA WALLA
PACIFIC OCEAN
PORTLAND
SALEM
IDAHO
EUGENE
OREGON
BOISE
LOCATION MAP
0
50
100
SCALE IN MILES
MEDFORD
KLAMATH FALLS
CALIFORNIA
NEVADA

Figure 1

Purpose and Need for Model Study

4. The purpose of the model study was to define the feasibility of the ECS and verify its competency as a regulating gate. The model study was required to provide hydrodynamic loading, flow conditions, and hydraulic characteristics associated with emergency closure as well as using the ECS as a regulating gate insuring the compatibility for dual purpose.

PART II: THE MODEL

Description

5. The proposed ECS, constructed to a scale of 1 to 50, consisted of seven bulkheads to be lowered in new slots in the upstream end of the lock. The initial bulkhead would be placed on cable-suspended lowering carriages in the slots. The remaining bulkheads would be stacked in the slots on top of the first one as the entire system was being lowered into the flow such that flow would be only under the stacked bulkheads. With the lock used as an auxiliary spillway, the closure bulkheads would be the control gate and the lock would function essentially as an energy dissipator.

6. The model included the 80-foot by 1,100-foot lock structure and 400 feet of approach upstream and downstream (photographs 1 and 2 and plates 3 and 4). The filling and emptying system of the lock was not reproduced. The lock gates were simulated in the open position by smooth walls in the model. The saltwater barrier (photograph 3) was simulated using only the minimum ballast required to maintain a down position which resulted in maximum sensitivity to flutter or rise with small pressure fluctuations. Piezometers for measuring pressure were placed in key locations (plates 3 and 4 and table A). The bottom bulkhead was reproduced in full detail both in size and shape of individual members and mass weight (plate 5) while the remaining bulkheads were reproduced only in general shape; however, they were reproduced to simulate correct mass (photograph 4). The three bottom bulkheads weighed 52.8 kips each, and the weight of the top four were 43.9 kips each. The bulkheads were lowered in a harness (a slot that moved with the bulkheads) to keep them free of sliding friction (photograph 5) to insure that hydraulic loading was isolated from friction loading. The lowering speed was 2 feet per minute (prototype). Forces on the cables were measured with SR-4 strain gages on a force ring and recorded to the nearest kip oscillographically.

Interpretation of Test Results

7. The following accepted equations of hydraulic similitude, based on Froudian relationship in which gravity is the dominant force, were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and the prototype.

Dimension	Ratio	Scale Relationship
Length	L_r	1:50
Area	$A_r = L_r^2$	1:2,500
Velocity	$V_r = L_r^{1/2}$	1:7.071
Time	$T_r = L_r^{1/2}$	1:7.071
Discharge	$Q_r = L_r^{5/2}$	1:17,667.67
Roughness	$N_r = L_r^{1/6}$	1:1.9194
Force	$F_r = L_r^3$	1:125,000
Weight	$W_r = L_r^3$	1:125,000

PART III: TESTS AND RESULTS

Emergency Closure System Mode

8. All tests were conducted with forebay pool el 22 feet, the maximum authorized elevation of Lake Union and Lake Washington. Tailwater was varied the full normal tide cycle from el -2 to el 12 feet.

9. The hydrodynamically induced downpull forces measured on the lowering cables as the bulkheads were placed for emergency closure are listed in table B. The forces were essentially the same with all tailwater levels. Control of the flow beneath the bulkheads remained at the sharp upstream bottom edge of the bottom bulkhead. Flow sprang free at that edge and did not impinge on the bottom members even at small submerged openings. The downpull forces gradually increased during lowering to a maximum of 20 kips at approximately 1 foot of opening. Downpull forces listed in table B were observed with the bulkheads continuously lowered at 2 feet per minute. When the bulkheads were placed to simulate prototype placement (lowering one to the point of near overflow, placing another on top, lowering again to the point of near overflow, and placing the others in like manner), the forces were the same as occurred during placement under continuous lowering during both the static and dynamic operating mode (table C). When bulkheads were held static in the flow, the forces remained the same as those developed during continuous lowering of the bulkheads as they passed through that position. The bulkheads were supported by the cable-suspended carriages attached to the bottom bulkhead and were unrestrained by friction, which permitted them maximum freedom to vibrate. No vibration occurred during lowering or during suspension at partial openings.

10. Hydraulic loading was also monitored with the bottom bulkhead modified by placing a solid plate over the upstream half of the bottom of the bottom bulkhead (photograph 6). With this bulkhead geometry, downpull forces during lowering were the same as those without the plate attached (table C). No vibration occurred with the partially plated bottom.

11. Individual bulkheads could not be placed successfully in the flow. An individual bulkhead could be lowered deep into the flow but would jam in the slots before seating. Cable forces measured during two attempts to place a single bulkhead are listed in table C. With flow over and under the bulkhead, downpull forces were as high as 51 kips. At an opening of 12 to 15 feet, the bulkhead began to be misalined in the slots and at an opening of approximately 5 feet became jammed.

Regulating Gate Mode

12. Water surface profiles, pressures, and velocities in the lock were measured with tailwater el -2, 5, and 12 feet with free flow and bulkhead openings of 28, 23, 18, 13, 8, and 3 feet. These data for low and high tailwater and various bulkhead openings are shown on plates 6 to 21. Flow conditions with free flow and openings of 23, 13, and 3 feet are shown in photographs 7 to 18.

13. The highest discharge and velocities occurred during free flow conditions with tailwater el -2 feet. Flow passed through critical depth (22.8 feet) at the upstream operating gate sill and was super-critical the full length of the lock chamber (plate 6 and photograph 7). A hydraulic jump occurred over the downstream gate sills. Maximum velocity along the floor and walls of the lock was 46 feet per second (fps) (plate 7). Maximum velocity on the channel bottom downstream from the lock chamber was 19 fps. All pressures were positive (plate 6).

14. The maximum local velocity and lowest pressure occurred with tailwater elevation -2 feet and a bulkhead opening of 8 feet (plates 10 and 11). Velocity on the floor just downstream from the bulkheads was 50 fps. Pressure just downstream from the existing closure system floor recess, (piezometer 7) was -17 feet of water. Pressure on the wall just downstream from the bulkhead slots was -6 feet (piezometer 4). The average pressure of -17 feet indicates a potential for cavitation exists in proximity of the floor recess during extreme conditions. Pressures at most measuring points fluctuated 1 to 2 feet of water with a maximum fluctuation of approximately 5 feet.

15. With the closure floor recess filled to the adjacent floor level, elevation -16 feet (photograph 19), the lowest pressures still

occurred with the 8-foot opening but were 6 and 9 feet of water at piezometers 7 and 4, respectively (tables D and E). The minimum pressure, which occurred downstream at piezometer A, was -7 feet of water — an acceptable level.

16. Piezometers were located on the right wall of the lock chamber near the upstream edge of the lock's four sets of miter gates. The piezometers were used to evaluate the effect of large discharges on the miter gates in an open condition to simulate operating the lock chamber as an auxiliary spillway. Pressures at those locations were approximately equal to the water depth in the chamber except at the two upstream miter gates during conditions of low tailwater and high velocity near the gates. Under the conditions, pressures were 2 to 10 feet less than the water depth (plates 8 and 22). These data indicate that at the higher velocity conditions, pressure in the recess behind the miter gates could be greater than pressures on the front face of the gate, thus tending to force the gates into the flow.

17. With almost all conditions observed, the saltwater barrier (simulated with minimum ballast) fluttered if not restrained. Sloped, low sills on the downstream edge of the barrier were tested first at the two sides and than across the full width of the barrier in an a attempt to prevent flutter; however, neither plan was successful. A deflector which diverted flow upward at the downstream face of the sill under the barrier away from the overhanging edge of the barrier was also ineffective. With a sharp-edged sill placed immediately upstream from the barrier to create a reduced pressure at the upstream edge and a sill placed under the downstream edge to minimize return flow under the barrier (plate 23), the barrier remained down and stable under all flow conditions. Neither sill alone was effective with all flow conditions. The downstream sill was required the full width of the lock to block return flow. The upstream sill must be the full 2-feet height of the barrier and a minimum of 2 inches upstream from the barrier to allow for barrier rotation into the raised position. The sill may be as much as 6 inches upstream and still be effective in lowering pressures beneath the barrier.

Discharge Rating

18. Discharge capacity of the lock free of tailwater effect with various forebay pool levels and bulkhead openings is shown on plate 24. The upper limits of effect of various tailwater levels are also shown. Below those limits the tailwater would reduce the discharge that would pass through the lock. The discharge with free flow conditions and three tailwater levels is shown on plate 25. The maximum discharge capacity of the lock with forebay el 22 feet is 48,700 cfs (free flow).

PART IV: SUMMARY

19. A 1:50 scale model was used to verify the design of an ECS and evaluate the same system for compatibility as a flood control regulating gate for Hiram M. Chittenden Locks at LWSC.

20. The bulkhead closure system proved acceptable both for emergency closure and as a regulating gate. Hydraulic downpull on the bulkheads was low (20 kips maximum), and no uplift occurred to prevent seating. The bulkheads did not vibrate during lowering or when suspended in the flow. The lock chamber functioned well as a spillway but would require some modifications, i.e., filling of the existing closure recess on the chamber floor, restraint of the miter gates against closure, and modification of the saltwater barrier prior to using as an auxiliary spillway.

TABLE A

PIEZOMETER LOCATIONS

Piezometer Number	Distance in Feet		Elevation
	From Downstream End of Lock	From Right (North) Wall	
1	E 1085.50	-3.23	-15
2	E 1083.40	0	-15
3	E 1082.15	0	-14
4	E 1080.65	0	-15
5	E 1085.50	45.00	-16
6	E 1075.50	45.00	-18
7	E 1059.50	45.00	-16
8	E 1042.50	0	-19
9	E 1042.00	45.00	-20
A	E 1007.50	45.00	-16
B	E 1001.00	60.00	-16
10	E 972.50	0	-20
11	E 972.00	45.00	-21
12	E 937.50	45.00	-16
13	E 919.89	45.00	-29
14	E 722.45	45.00	-29
15	E 522.00	0	-33
16	E 522.00	45.00	-34
17	E 487.50	45.00	-29
18	E 320.63	45.00	-29
19	E 147.00	0	-33
20	E 13.00	0	-33
21	E 13.00	45.00	-34

NOTE: Piezometer locations shown on plates 3 and 4.

TABLE B

HYDRODYNAMIC DOWNPULL FORCES ON BULKHEADS

Forebay El 22
Original Design Bulkheads

Bulkhead Opening in Feet	Tailwater Elevation											
	-2				1		5		9		12	
	Force in Kips											
	Run 1	Run 2	Run 3	Run 4	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
32.0	0	0	0	0	0	0	0	0	0	0	0	0
31.0	1	0	1	1	1	1	1	1	0	1	1	1
26.0	2	2	3	2	3	2	2	2	1	2	2	2
21.0	3	4	5	3	4	3	3	4	2	4	4	3
16.0	4	5	7	5	6	4	5	5	3	5	6	4
11.0	5	7	9	6	8	6	7	7	4	7	8	5
6.0	11	13	14	13	14	11	14	13	10	12	12	17
1.0	16	20	19	19	20	17	20	19	16	17	16	20
0.1	16	19	19	19	19	16	19	20	14	16	16	20
0	0	0	0	0	0	0	0	0	0	0	0	0

NOTE: Bulkheads lowered at 2 fpm without stopping.

TABLE B

TABLE C

HYDRODYNAMIC DOWNPULL FORCES ON BULKHEADS

Forebay El 22

Bulkhead Opening in Feet	Original Design Bulkheads			Upstream Half of Bottom of Bottom Bulkhead Plated			
	Bulkheads Added One at a Time	Single Bulkhead Lowered		Bulkheads Lowered Without Stopping			
	Tailwater Elevation						
	5	12		-2		12	
	Force in Kips						
	Run 1	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
32.0	0	0	0	0	0	0	0
31.0	1	9	10	1	1	1	1
26.0	2	31	36	2	2	2	2
21.0	4	42	51	3	4	4	4
16.0	5	41	50	5	6	6	6
11.0	7	11	16	6	8	8	7
6.0	12	-19	-17	13	14	13	13
1.0	18	-26	-24	20	20	18	18
0.1	18	-26	-25	20	19	17	18
0	0			0	0	0	0

TABLE C

TABLE D

PRESSURES

Existing Closure Floor Recess Filled
Forebay El 22, Tailwater El -2

Piezometer Number	Lock Discharge in CFS						
	48,700	45,500	41,500	35,780	27,860	18,330	6,430
	Bulkhead Opening in Feet						
	Free Flow	28	23	18	13	8	3
	Pressure in Feet of Water						
1	25	29	32	33	30	21	24
2	25	21	19	27	13	8	5
3	24	21	17	25	12	7	4
4	25	23	23	22	16	9	6
5	25	21	18	16	16	15	4
7	28	21	17	15	10	6	7
8	30	22	17	13	9	4	12
9	32	22	18	14	9	6	13
A	29	20	15	10	1	-7	9
B	28	21	17	13	5	0	10
10	27	26	23	19	16	12	17
11	27	26	23	20	17	13	18
12	17	21	17	14	10	5	13
13	21	21	19	17	15	22	27

NOTE: Piezometer locations shown on plates 3 and 4.

TABLE E

PRESSURES

Existing Closure Floor Recess Filled
Forebay El 22, Tailwater El 5

Piezometer Number	Lock Discharge in CFS						
	48,700	45,500	41,500	35,780	27,860	18,330	5,360
	Bulkhead Opening in Feet						
	Free Flow	28	23	18	13	8	3
	Pressure in Feet of Water						
1	25	29	32	33	30	21	28
2	25	21	18	17	13	9	15
3	24	20	17	15	12	7	13
4	25	23	23	21	16	9	17
5	25	20	18	16	16	15	18
7	28	21	17	15	10	6	18
8	30	22	18	13	9	14	23
9	32	22	18	13	10	13	23
A	29	20	15	9	2	12	20
B	28	21	17	13	6	15	20
10	27	26	23	20	17	22	25
11	27	26	23	21	19	22	26
12	17	21	18	16	14	18	21
13	21	22	22	24	29	32	34

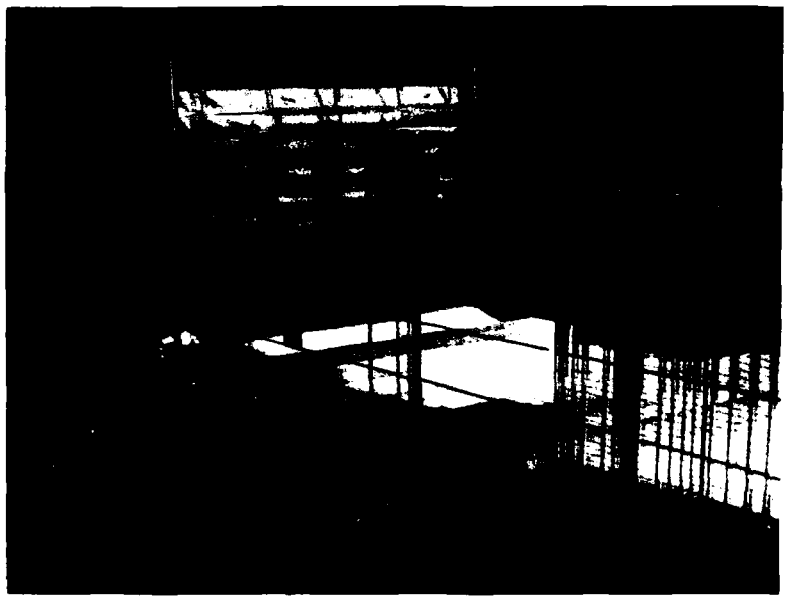
NOTE: Piezometer locations shown on plates 3 and 4.

Photograph 1

Lake Washington Ship Canal Lock Model
Looking upstream

Upstream

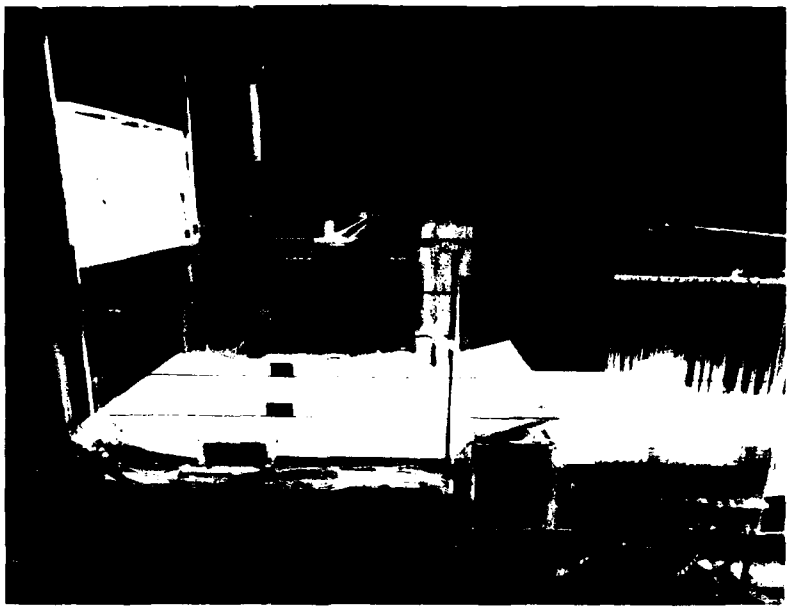
Closure bulkheads



Saltwater barrier

Photograph 2

Lock chamber

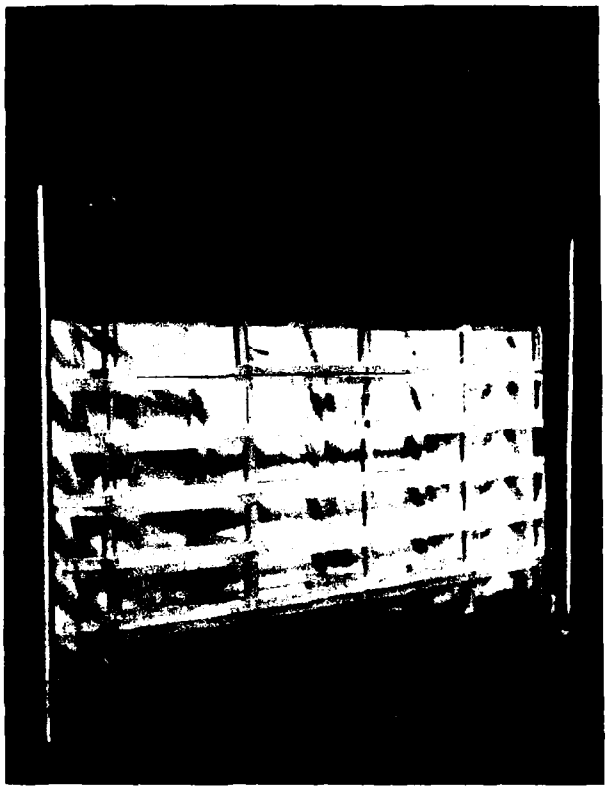


Closure recess

Saltwater barrier
(partially raised)

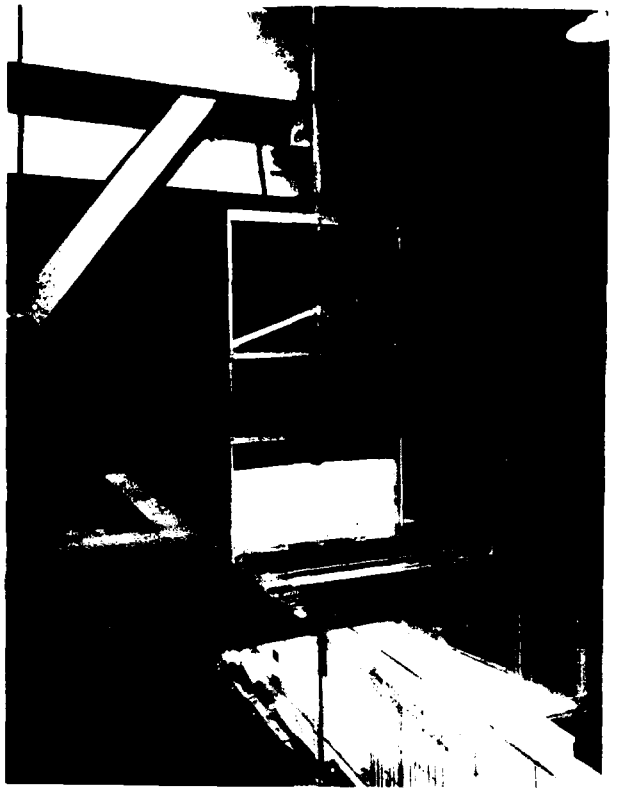
Photograph 3

Existing lock floor



Photograph 4

Emergency closure bulkheads stacked in model lowering harness
Downstream face

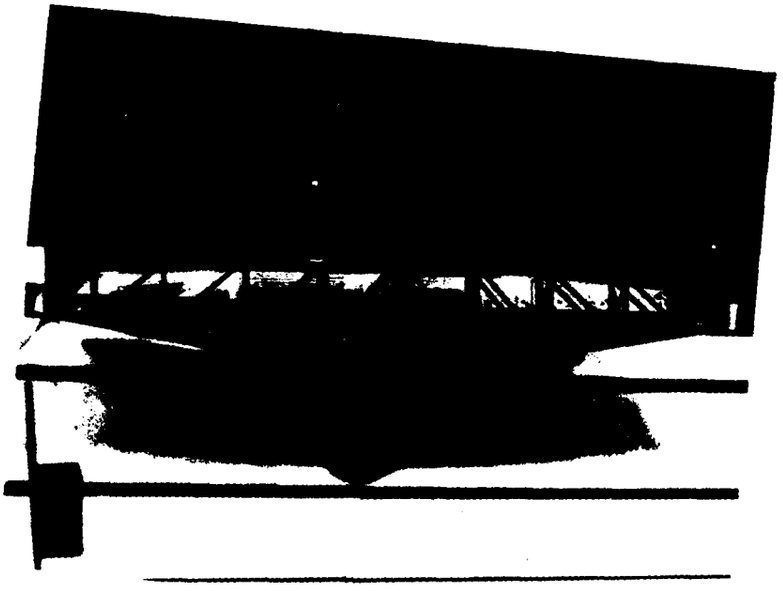


Downstream face

Upstream face

Photograph 5

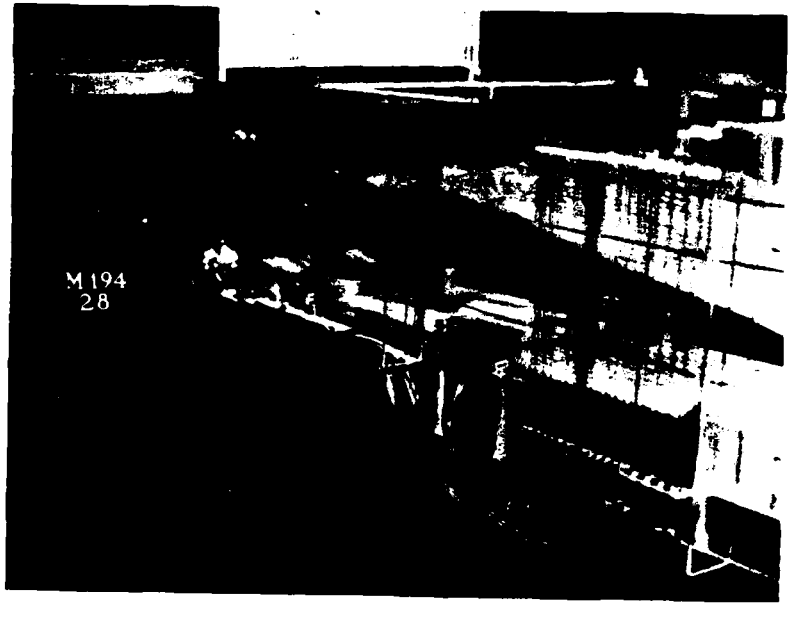
Emergency closure bulkheads stacked in model lowering harness
suspended from lowering mechanism with force measuring ring



Photograph 6
Bottom of bottom bulkhead with flat plate on upstream half

Closure bulkheads

Downstream gate sills



Closure area and upstream gate sills

Photograph 7

Flow through lock chamber
Forebay el 22, tailwater el -2, free flow, discharge 48,700 cfs

Closure bulkheads

Downstream gate sills

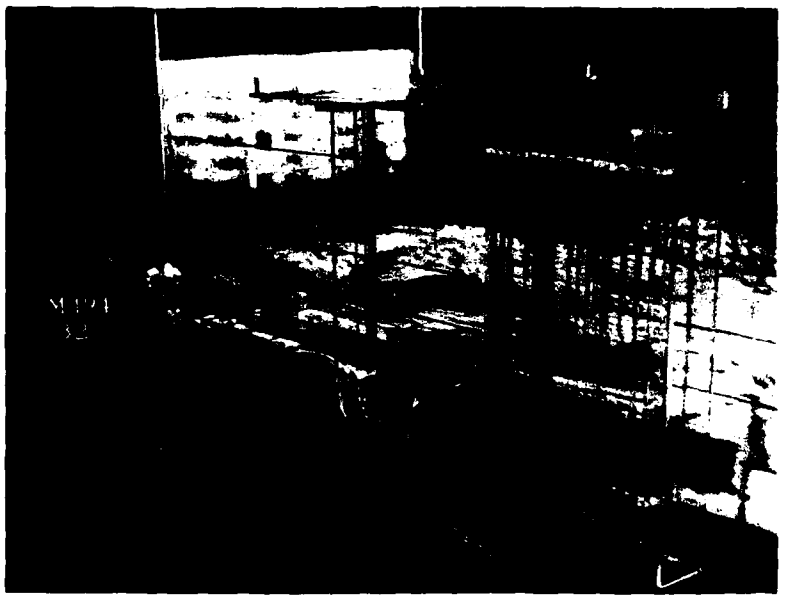
Closure area and upstream gate sills

Photograph 8

Flow through lock chamber
Forebay el 22, tailwater el -2, bulkhead opening 23 ft, discharge 41,500 cfs

Closure bulkheads

Downstream gate sills



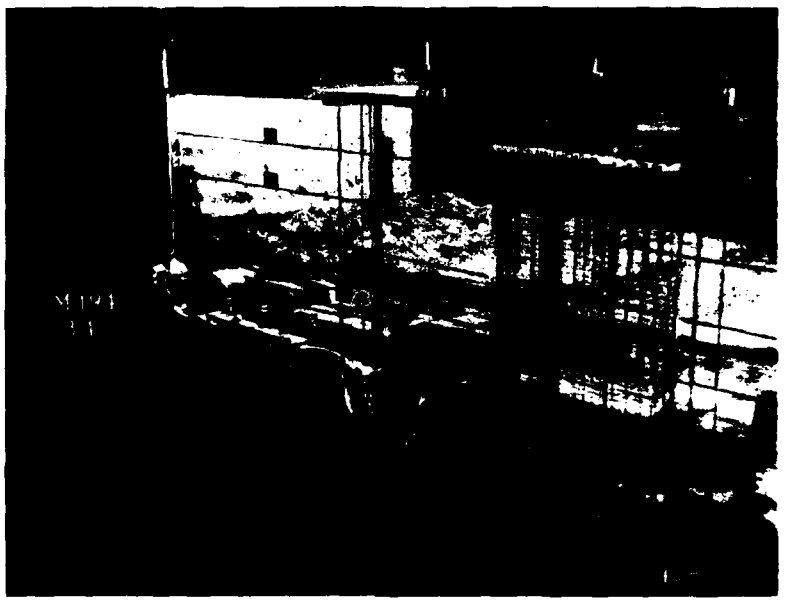
Closure area and upstream gate sills

Photograph 9

Flow through lock chamber
Forebay el 22, tailwater el -2, bulkhead opening 13 ft, discharge 27,860 cfs

Closure bulkheads

Downstream gate sills



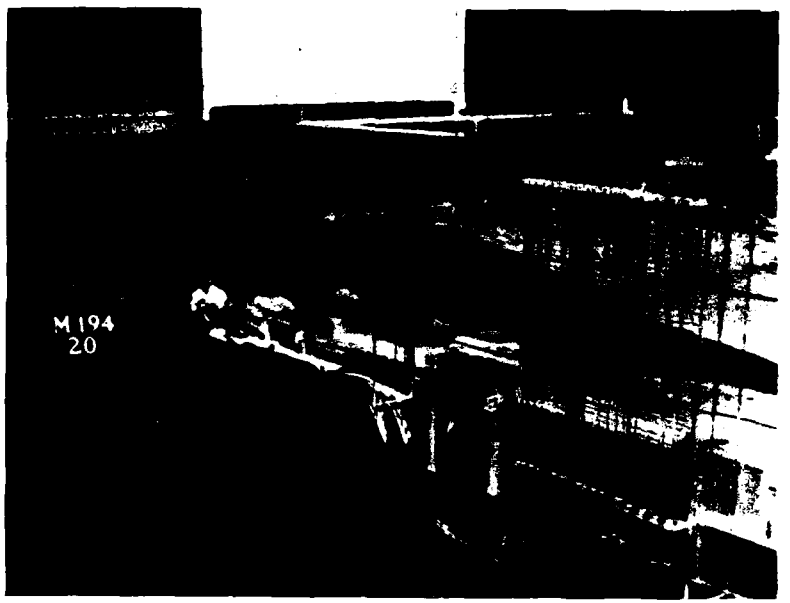
Closure area and upstream gate sills

Photograph 10

Flow through lock chamber
Forebay el 22, tailwater el -2, bulkhead opening 3 ft, discharge 6,430 cfs

Closure bulkheads

Downstream gate sills



Closure area and upstream gate sills

Photograph 11

Flow through lock chamber
Forebay el 22, tailwater el 5, free flow, discharge 48,700 cfs

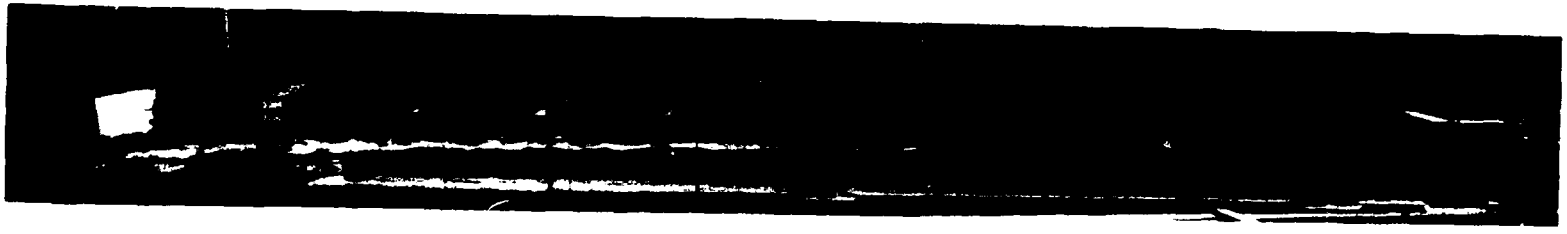
Closure bulkheads

Downstream gate sills

Closure area and upstream gate sills

Photograph 12

Forebay el 22, tailwater el 5, bulkhead opening 23 ft, discharge 41,500 cfs



Closure bulkheads

Downstream gate sills

Closure area and upstream gate sills

Photograph 13

Flow through lock chamber
Forebay el 22, tailwater el 5, bulkhead opening 13 ft, discharge 27,860 cfs

Closure Bulkheads

Downstream gate sills

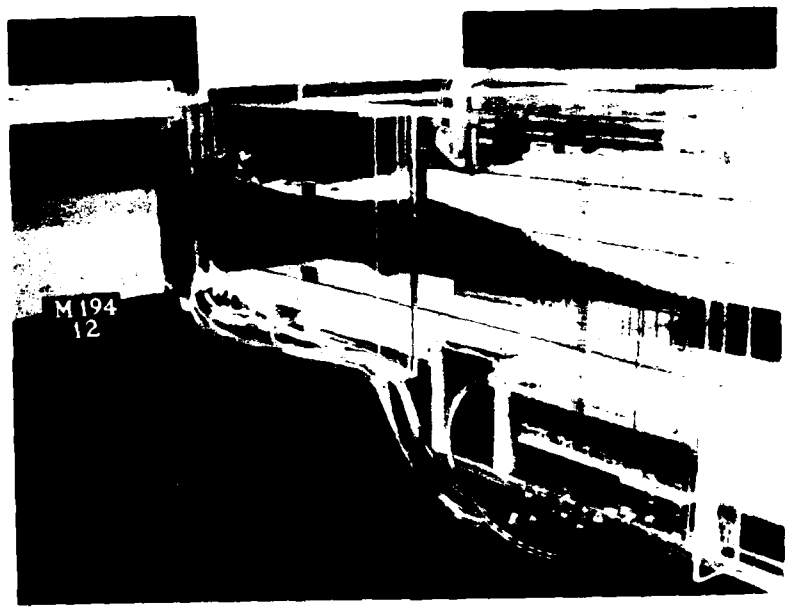
Closure area and upstream gate sills

Photograph 14

Flow through lock chamber
Forebay el 22, tailwater el 5, bulkhead opening 3 ft, discharge 5,360 cfs

Closure bulkheads

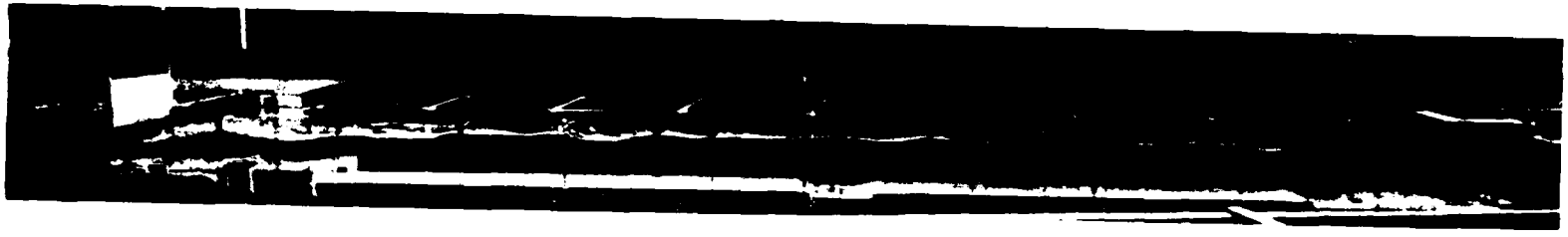
Downstream gate sills



Closure area and upstream gate sills

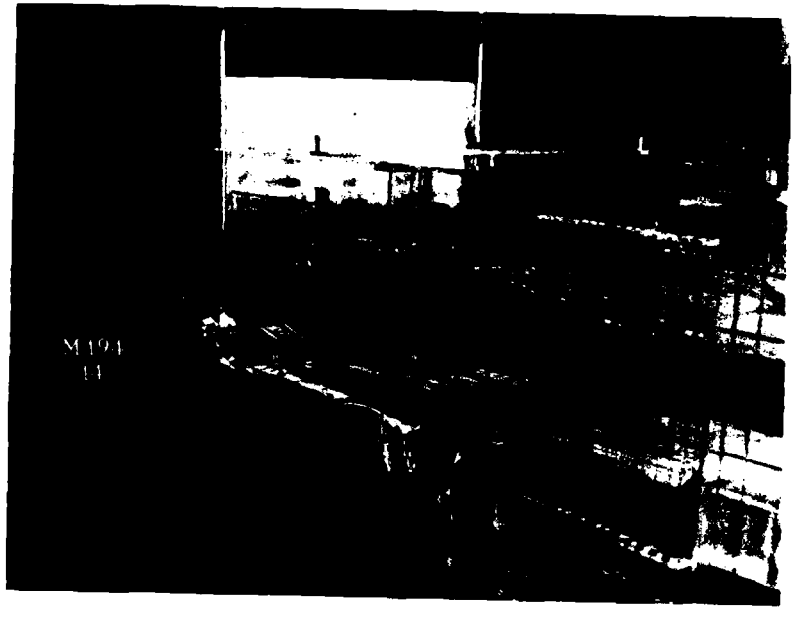
Photograph 15

Flow through lock chamber
Forebay el 22, tailwater el 12, free flow, discharge 48,700 cfs



Closure bulkheads

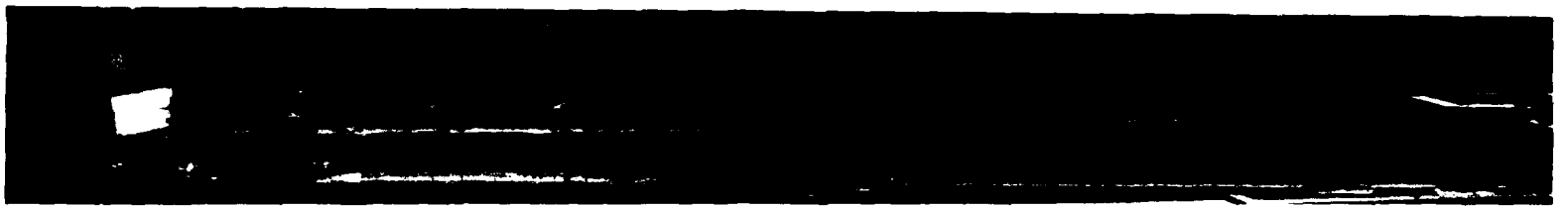
Downstream gate sills



Closure area and upstream gate sills

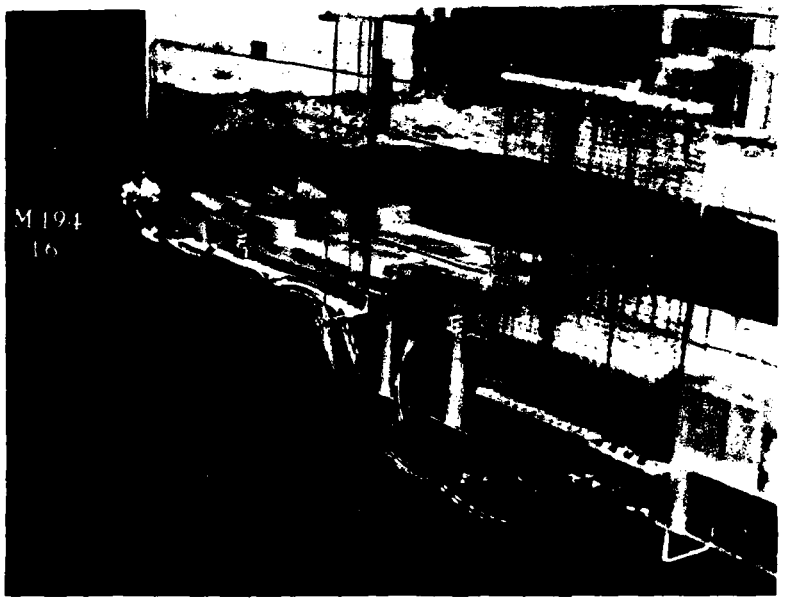
Photograph 16

Flow through lock chamber
Forebay el 22, tailwater el 12, bulkhead opening 23 ft, discharge 41,500 cfs



Closure bulkheads

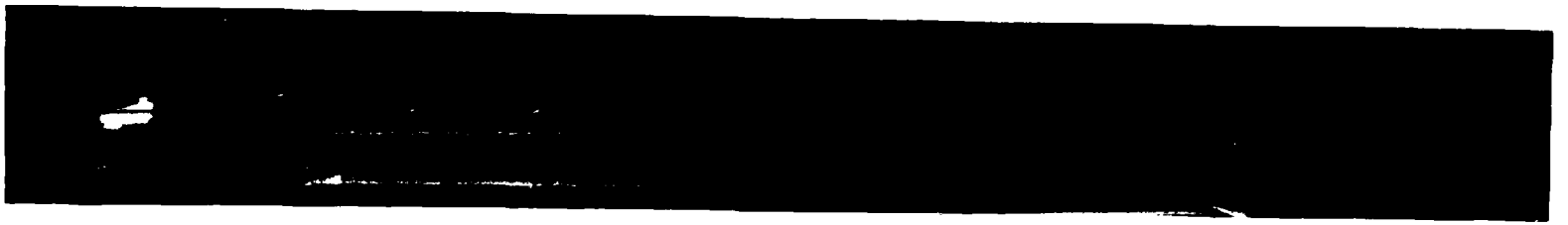
Downstream gate sills



Closure area and upstream gate sills

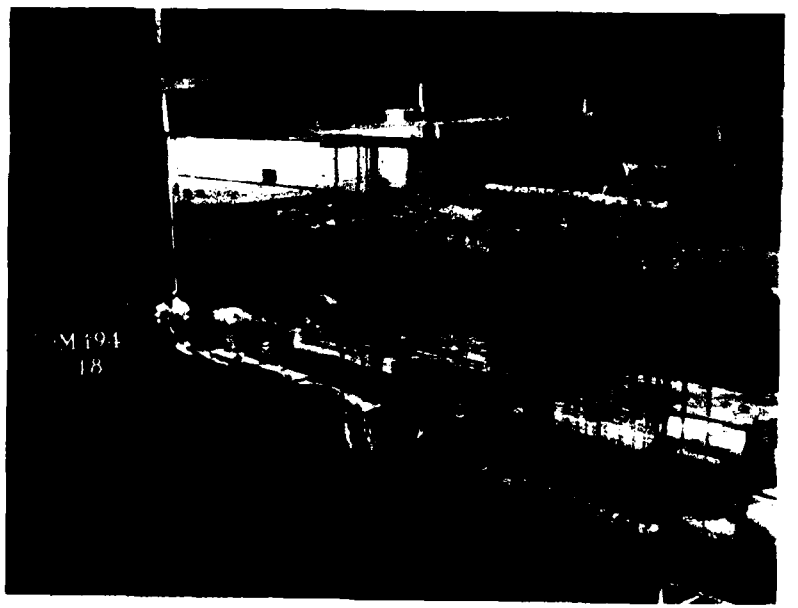
Photograph 17

Flow through lock chamber
Forebay el 22, tailwater el 12, bulkhead opening 13 ft, discharge 21,500 cfs



Closure bulkheads

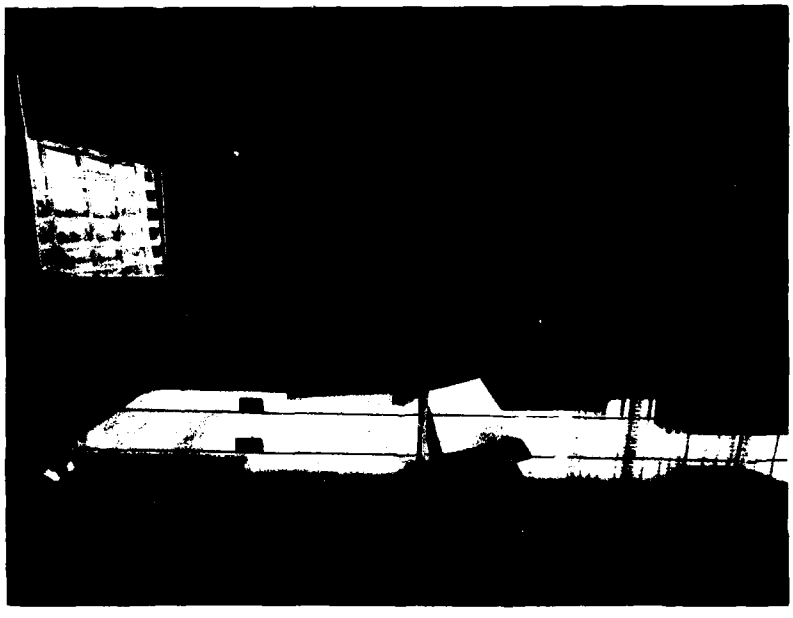
Downstream gate sills



Closure area and upstream gate sills

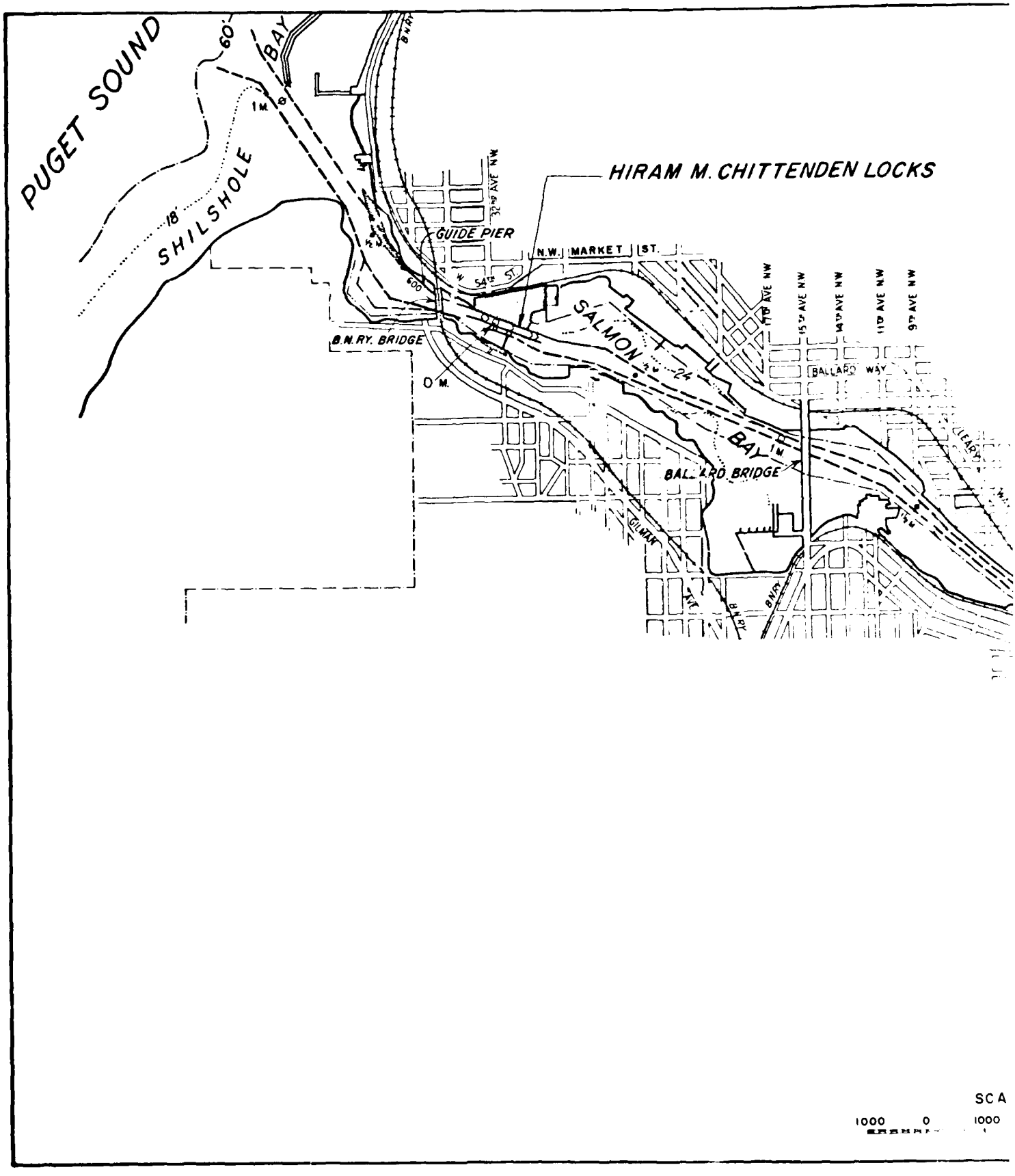
Photograph 18

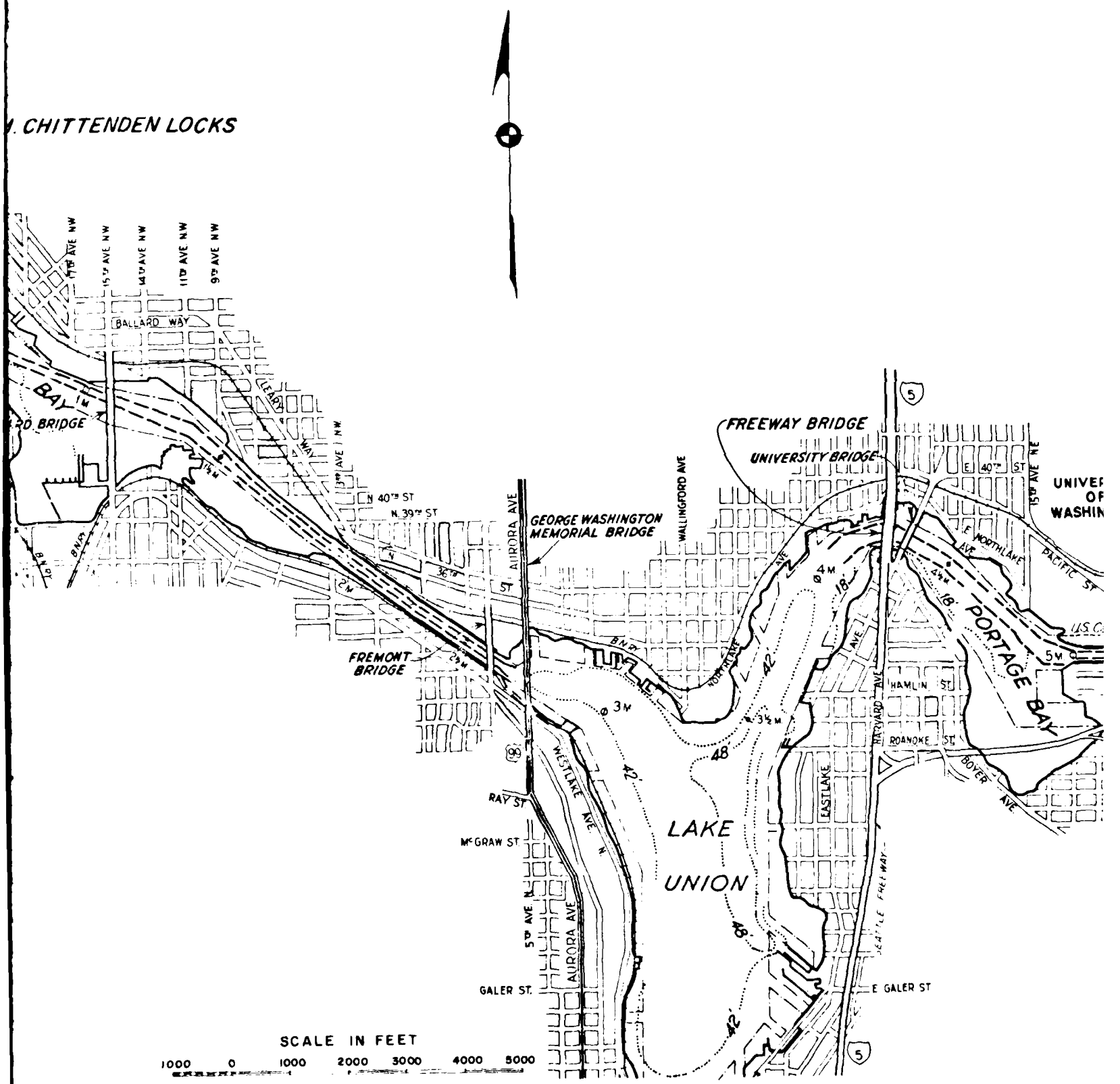
Flow through lock chamber
Forebay el 22, tailwater el 12, bulkhead opening 3 ft, discharge 4,100 cfs

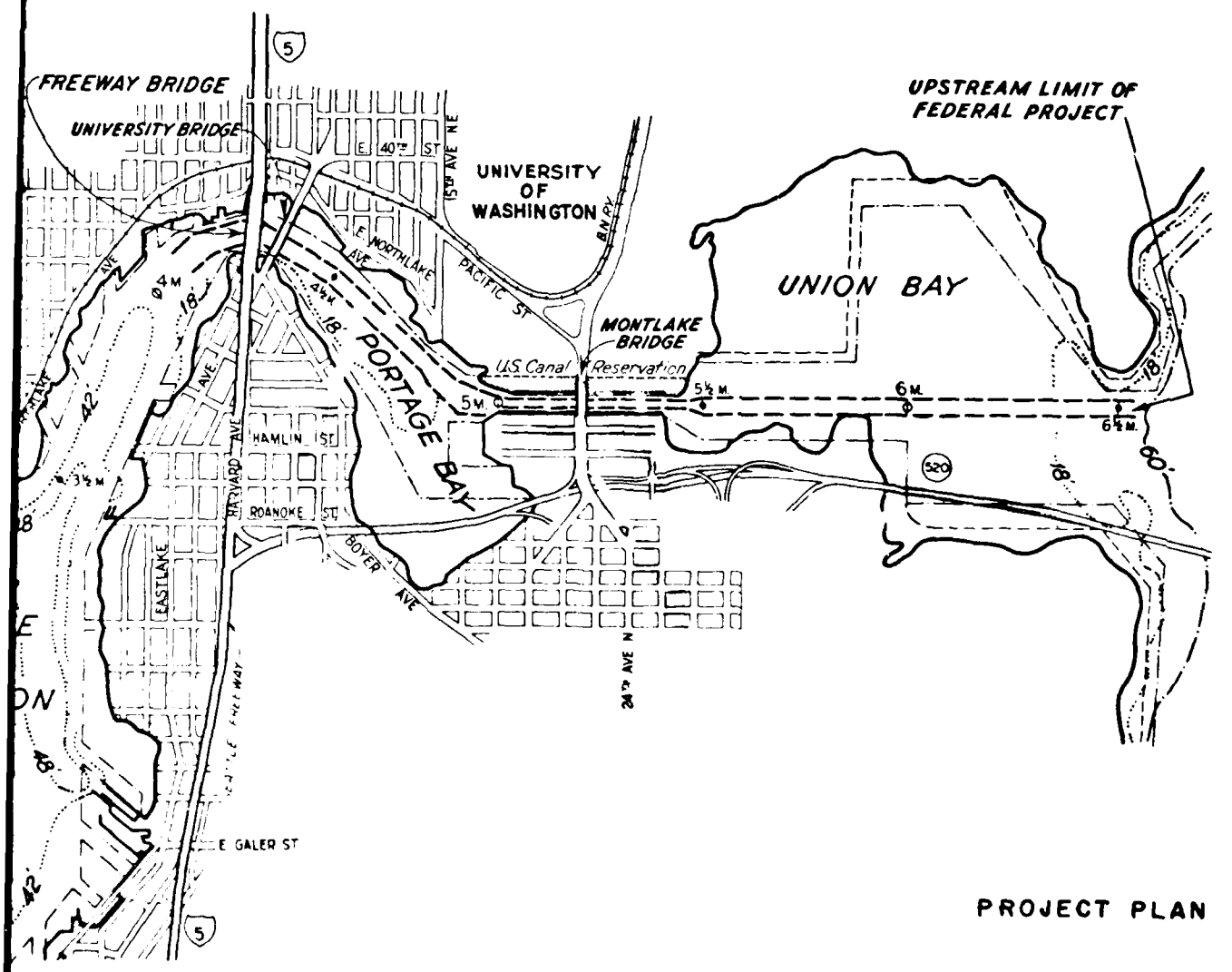


Photograph 19

Proposed modification in gate closure recess
on floor of lock chamber

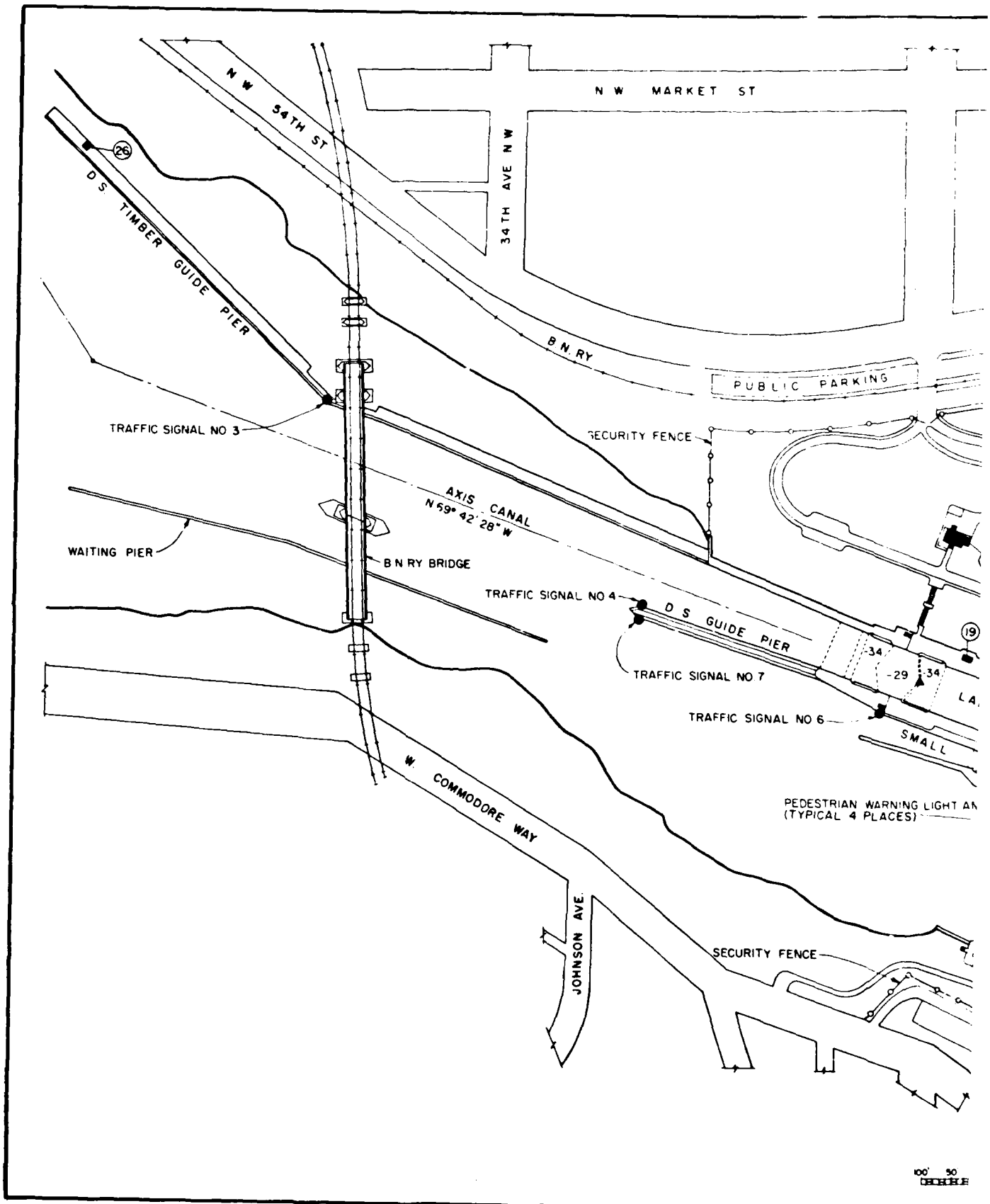

PUGET SOUND
60'
BAY
1M
18'
SHILSHOLE
HIRAM M. CHITTENDEN LOCKS
GUIDE PIER
32nd AVE N.W.
N.W. MARKET ST.
54th
51st
600
B.N.RY. BRIDGE
0 M.
SALMON BAY
24
1M
BALLARD BRIDGE
BALLARD WAY
17th AVE N.W.
15th AVE N.W.
14th AVE N.W.
11th AVE N.W.
9th AVE N.W.
GILMAN
B.N.RY.
SCA
1000 0 1000

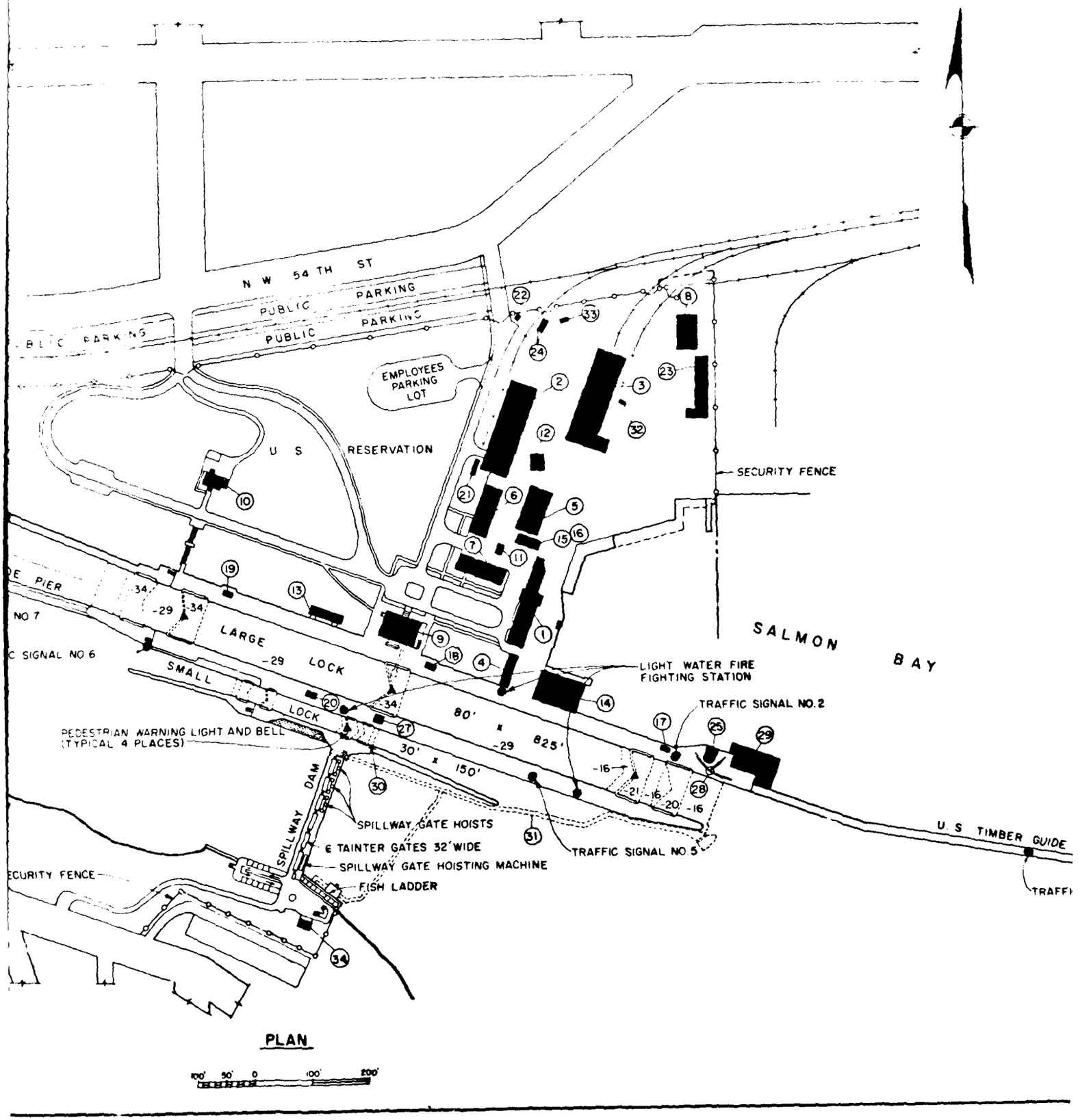

CHITTENDEN LOCKS
BAY
BALLARD WAY
LEARY WAY NW
N 40TH ST
N 39TH ST
GEORGE WASHINGTON MEMORIAL BRIDGE
AURORA AVE
FREMONT BRIDGE
FREEWAY BRIDGE
UNIVERSITY BRIDGE
WALLINGFORD AVE
E 40TH ST
15TH AVE NE
NORTHLAKE AVE
PACIFIC ST
PORTAGE BAY
HAMLIN ST
ROANOKE ST
BOYER AVE
HARVARD AVE
EASTLAKE AVE
WESTLAKE AVE N
RAY ST
McGRAW ST
GALER ST
E GALER ST
5TH AVE N
LAKE UNION
SEATTLE FREEWAY
SCALE IN FEET
1000 0 1000 2000 3000 4000 5000



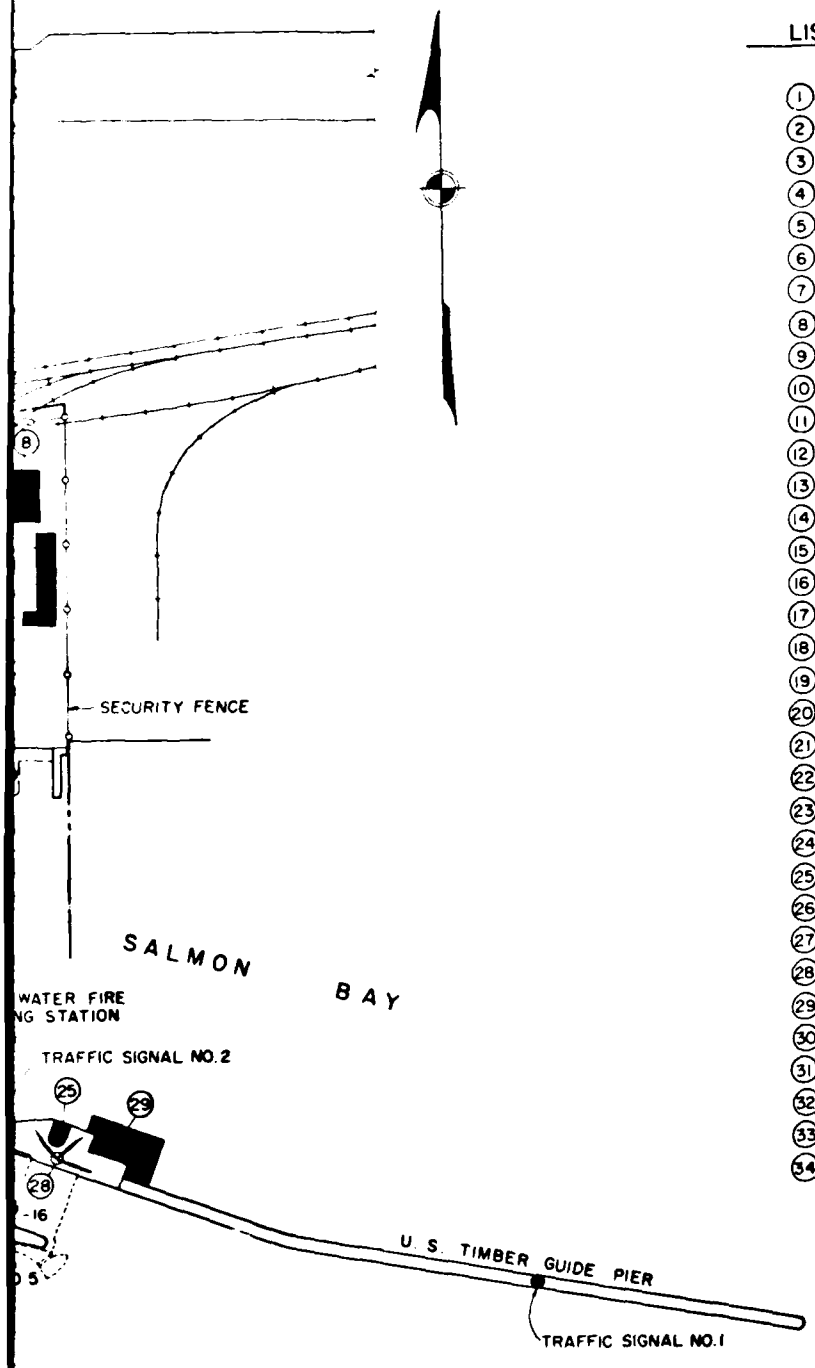
PROJECT PLAN

PLATE 1


N W MARKET ST
N W 54TH ST
34TH AVE N W
D S TIMBER GUIDE PIER
B N RY
PUBLIC PARKING
TRAFFIC SIGNAL NO 3
SECURITY FENCE
AXIS CANAL
N 59° 42' 28" W
WAITING PIER
B N RY BRIDGE
TRAFFIC SIGNAL NO 4
D S GUIDE PIER
TRAFFIC SIGNAL NO 7
TRAFFIC SIGNAL NO 6
SMALL
PEDESTRIAN WARNING LIGHT AN
(TYPICAL 4 PLACES)
W COMMODORE WAY
JOHNSON AVE.
SECURITY FENCE
100' 50


N W 54 TH ST
PUBLIC PARKING
PUBLIC PARKING
PUBLIC PARKING
EMPLOYEES PARKING LOT
U S RESERVATION
SECURITY FENCE
SALMON BAY
LARGE LOCK
-29
SMALL LOCK
-34
80' x 825'
30' x 150'
-29
-34
-16
-21
-20
DAM
SPILLWAY
PEDESTRIAN WARNING LIGHT AND BELL (TYPICAL 4 PLACES)
SPILLWAY GATE HOISTS
6 TAINTER GATES 32' WIDE
SPILLWAY GATE HOISTING MACHINE
FISH LADDER
LIGHT WATER FIRE FIGHTING STATION
TRAFFIC SIGNAL NO. 2
TRAFFIC SIGNAL NO. 5
U S TIMBER GUIDE
E PIER
NO 7
C SIGNAL NO 6
ECURITY FENCE
100' 50' 0 100' 200'

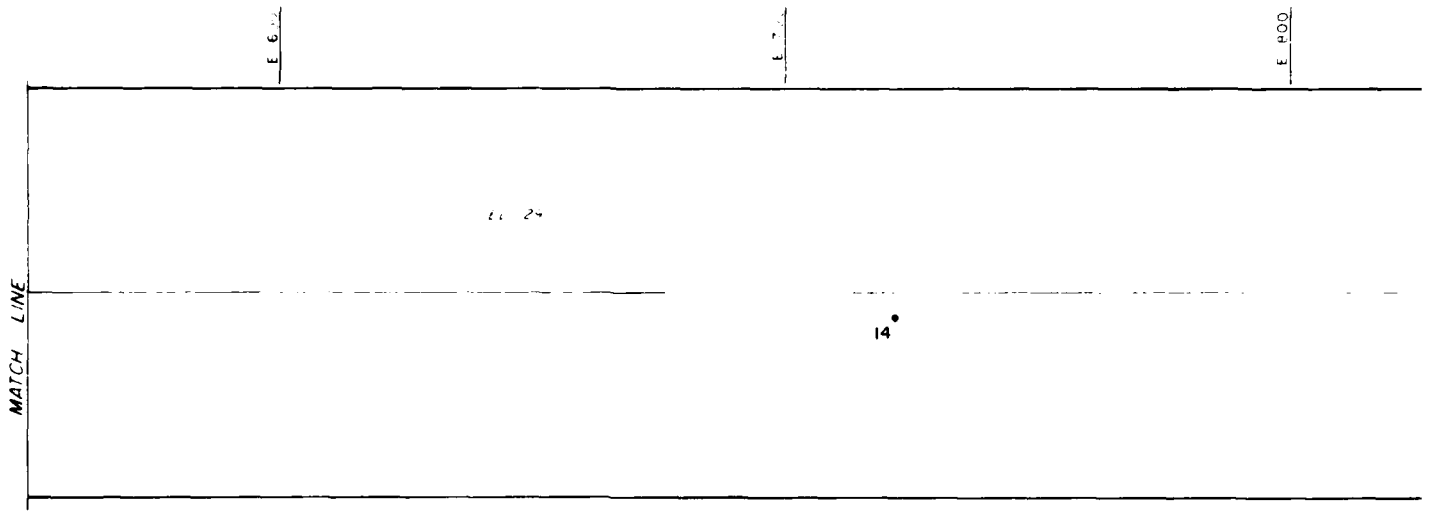
PLAN

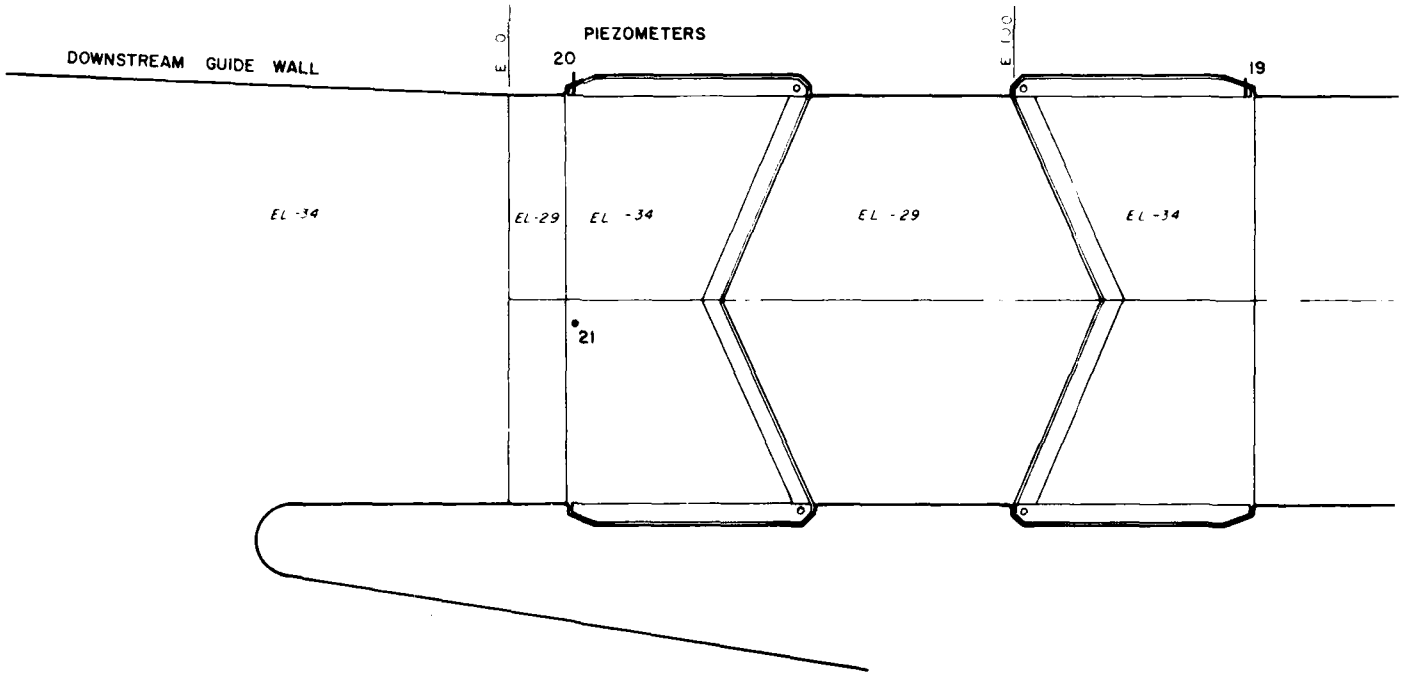


LIST OF BUILDINGS OR STRUCTURES

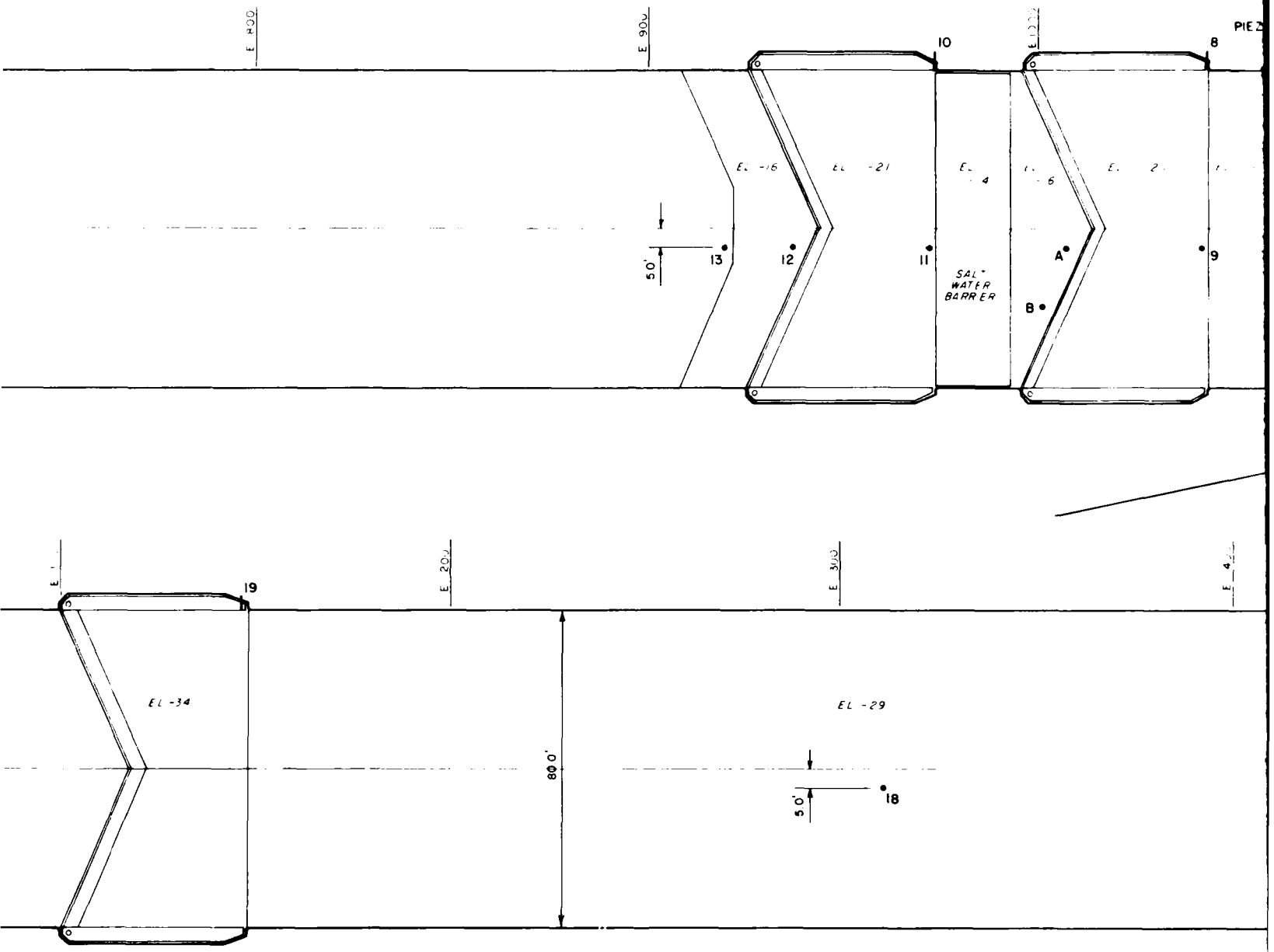
1. Office and Shop Building
2. Warehouse No 2
3. Gararge
4. Mechanics Shop
5. Steel Shop
6. Carpenter and Blacksmith Shops
7. Machine Shop
8. Quonset Hut
9. Administration Building
10. District Engineer's Residence
11. Gas and Oil Building
12. Transformer House
13. Public Comfort Station
14. Boathouse
15. Greenhouse
16. Greenhouse
17. Operating House No 1
18. Operating House No 2
19. Operating House No 3
20. Operating House No 4
21. Wood Storage Shed
22. Gatehouse
23. Open Storage Shed
24. Propane Storage
25. Emergency Dam Hoist House
26. T V Camera Pylon
27. Control Tower
28. 75-Ton Crane
29. Emergency Dam Storage
30. Emergency Dam and Derrick
31. Salt Water Siphon
32. Gas Pump
33. Transformer Station
34. Public Comfort Station

GENERAL LAYOUT



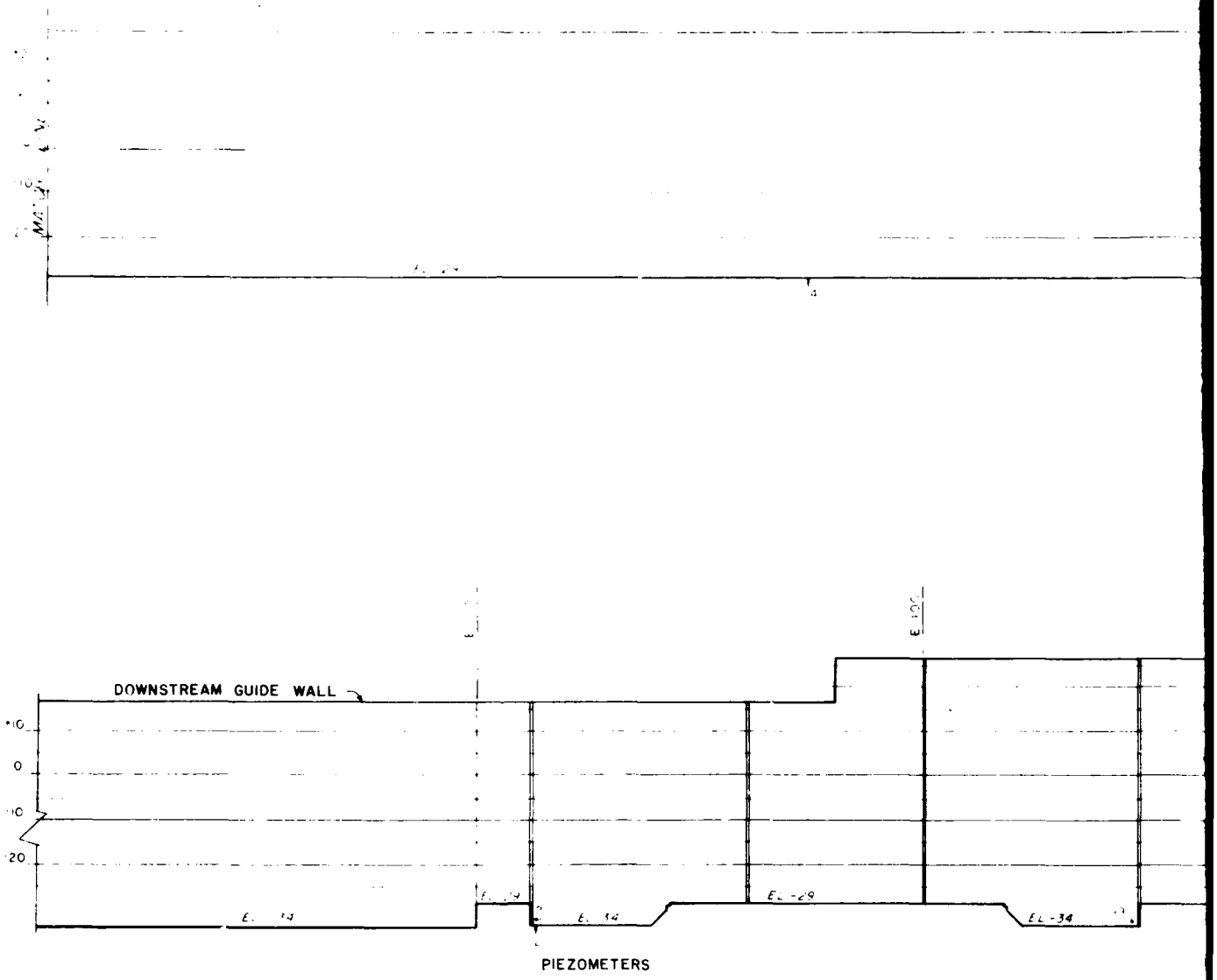


NOTE: PIEZOMETER LOCATIONS LISTED IN TABLE A

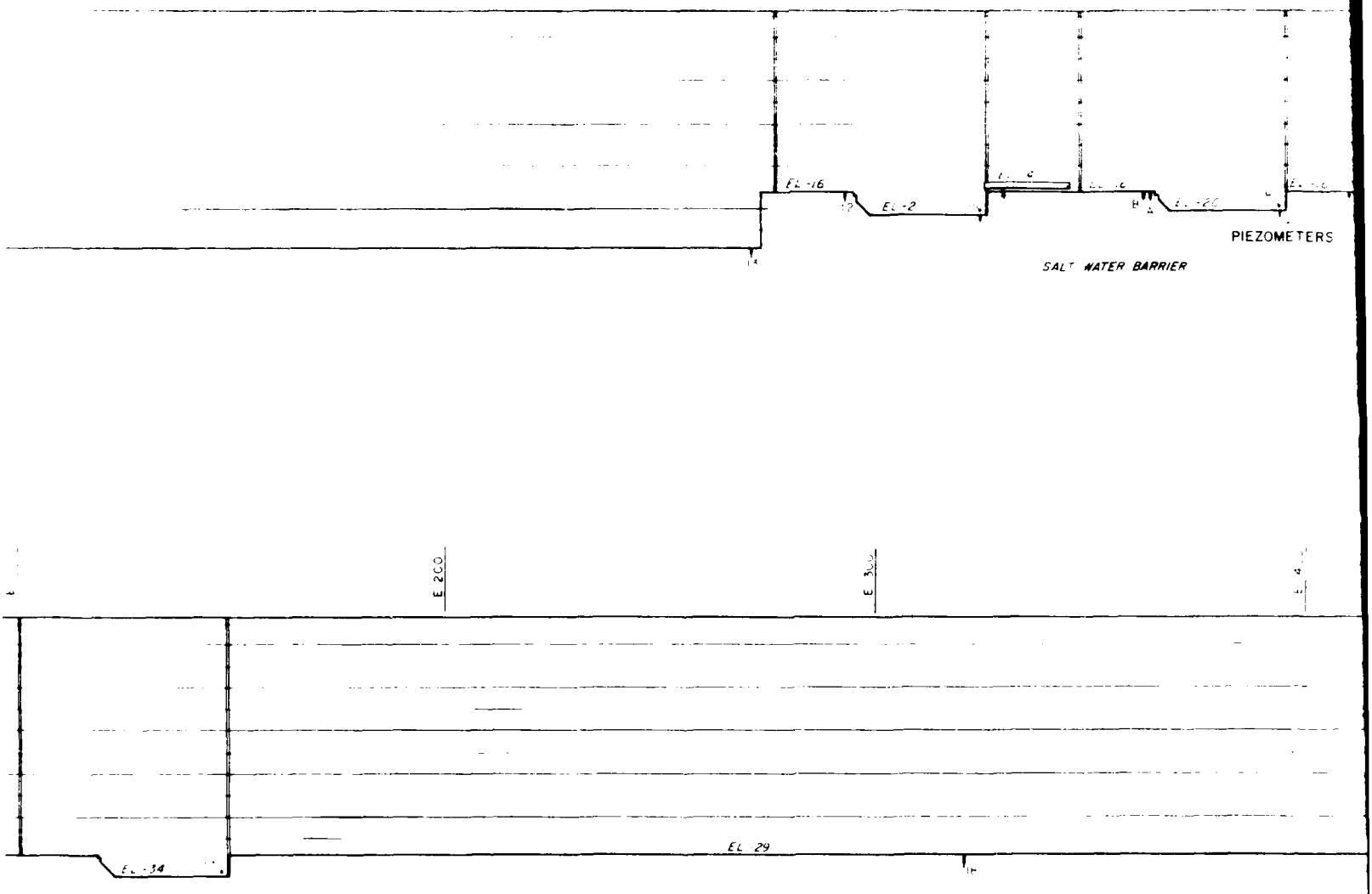

E 800
E 900
E 1200
PIEZ
10
8
EL -16
EL -21
E 4
6
E 2
50'
13
12
11
A
9
SALT WATER BARRIER
B
E 2000
E 3000
19
EL -34
EL -29
800'
50'
18

PLAN

2



NOTE: PIEZOMETER LOCATIONS
LISTED IN TABLE A

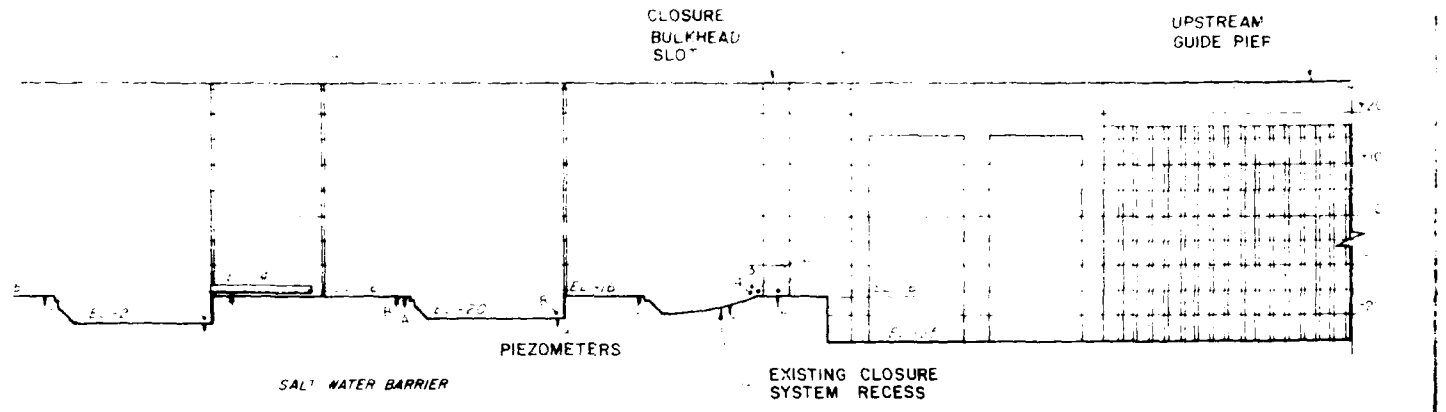


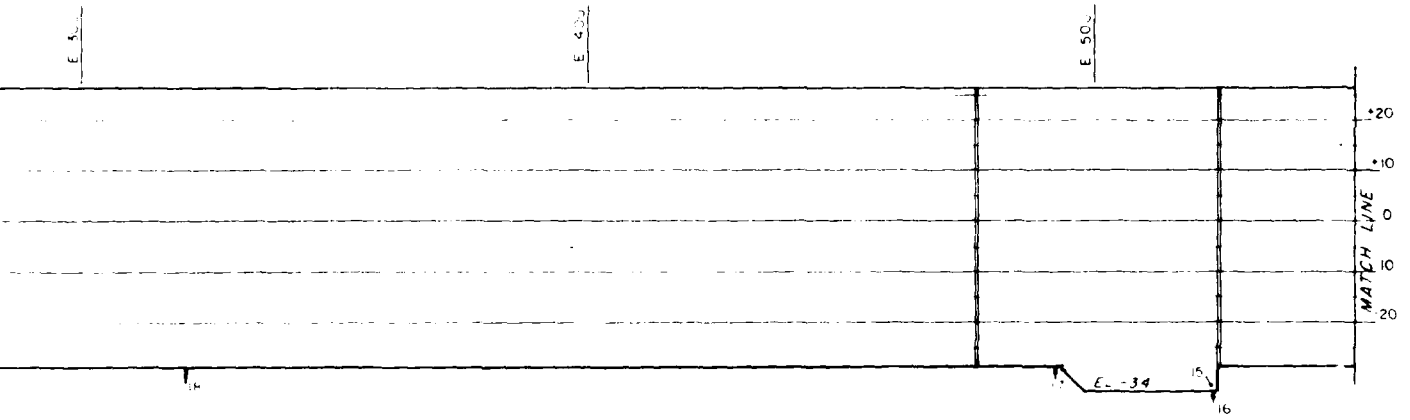
SECTION ALONG CENTER LINE OF LOCK

LEGEND

—— WATER-SURFACE PROFILE ALONG RIGHT WALL

(26) PRESSURE IN FEET OF WATER



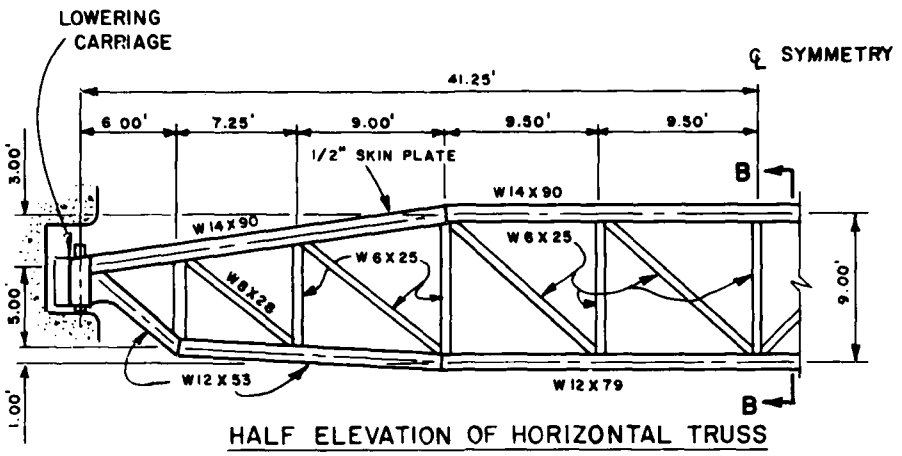


LINE OF LOCK

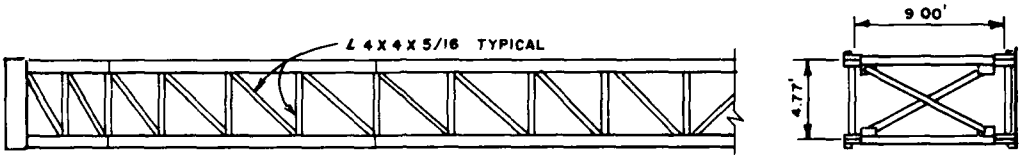
MODEL DETAILS AND
PIEZOMETER LOCATIONS

3

PLATE 4



HALF ELEVATION OF HORIZONTAL TRUSS



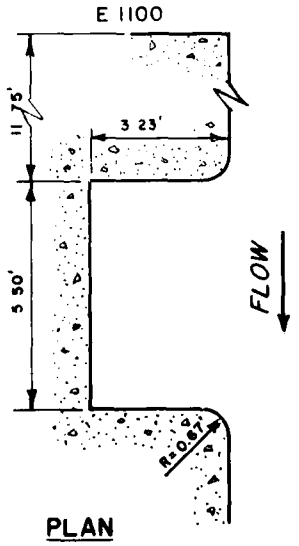
HALF ELEVATION OF VERTICAL TRUSS

SECTION B-B

BOTTOM BULKHEAD

NOTE

TOP FOUR BULKHEADS HAVE LIGHTER MEMBERS, OTHER TWO SAME AS BOTTOM.

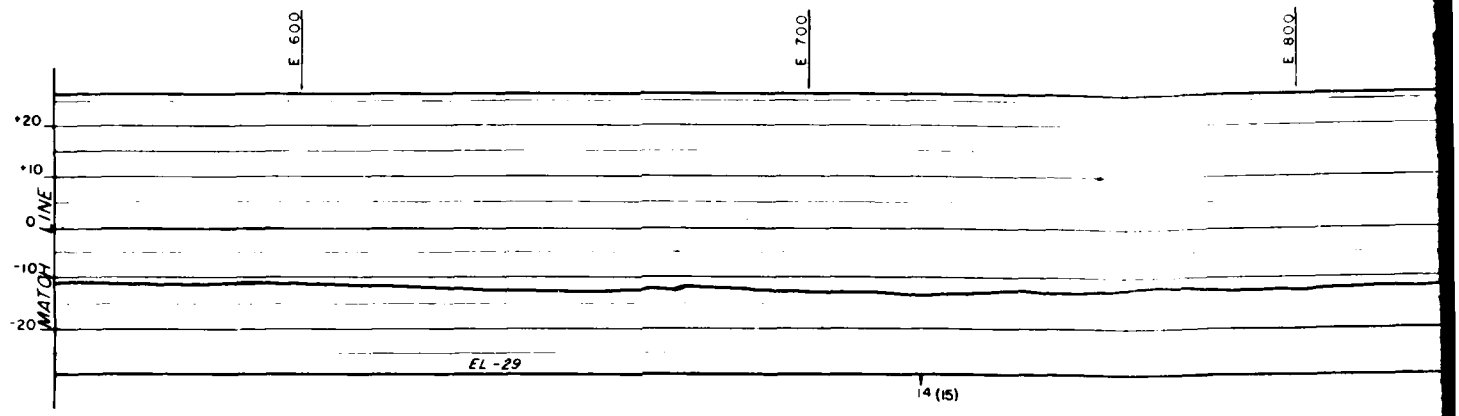


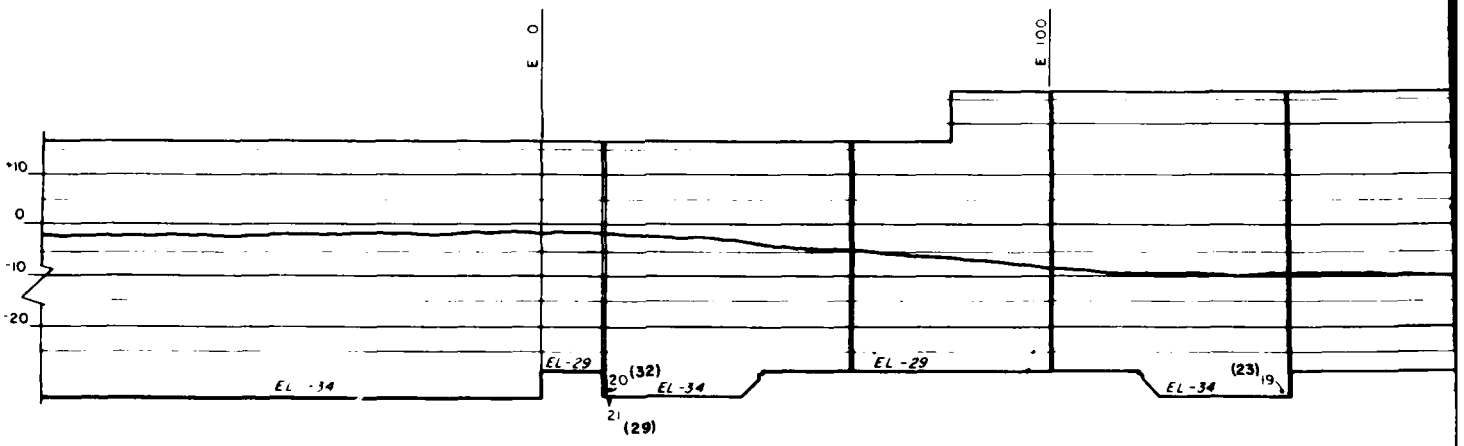
PLAN

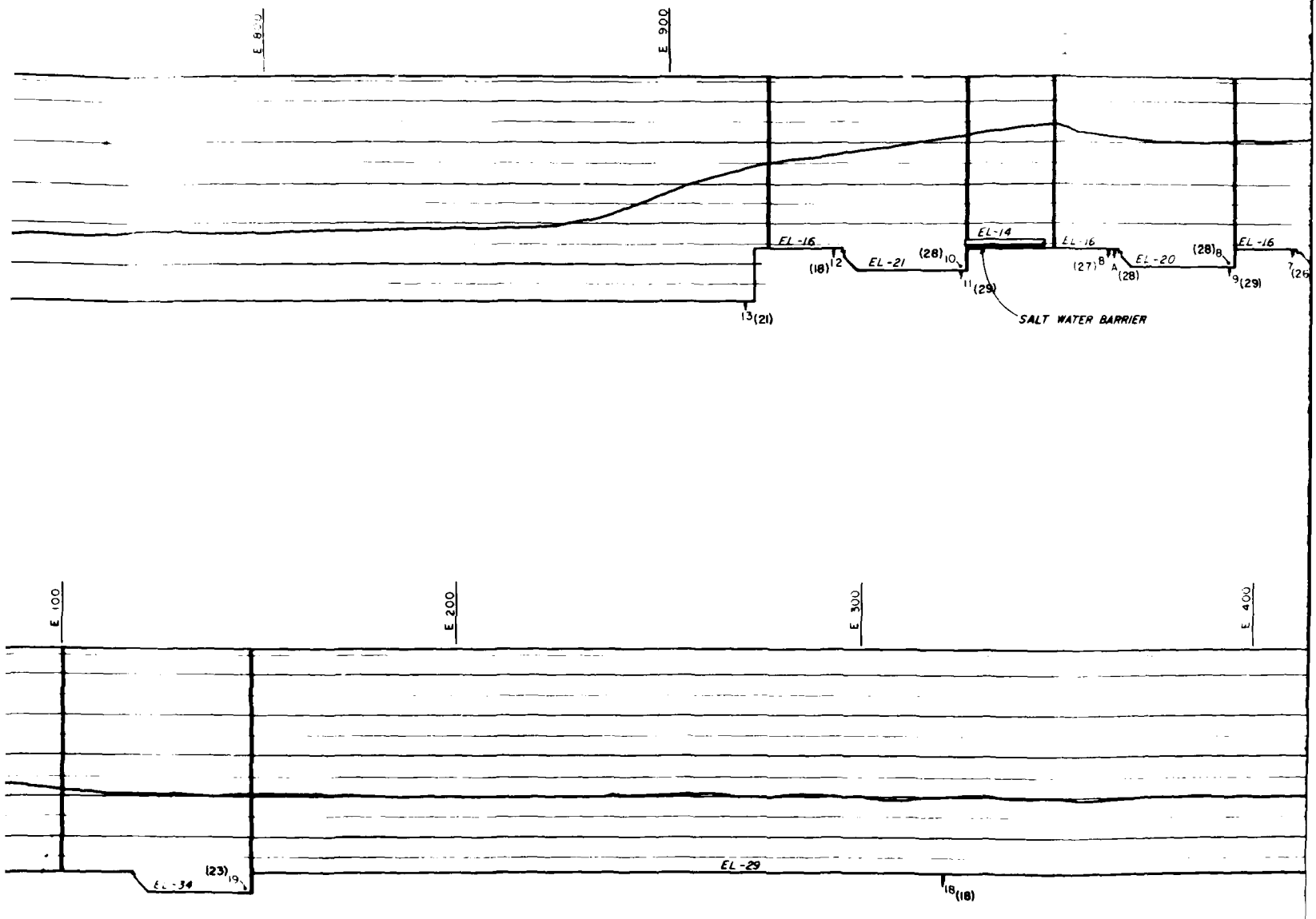
BULKHEAD SLOT

BOTTOM BULKHEAD AND SLOT

PLATE 5


E 600
E 700
E 800
+20
+10
0
-10
-20
MATCH LINE
EL -29
14 (15)

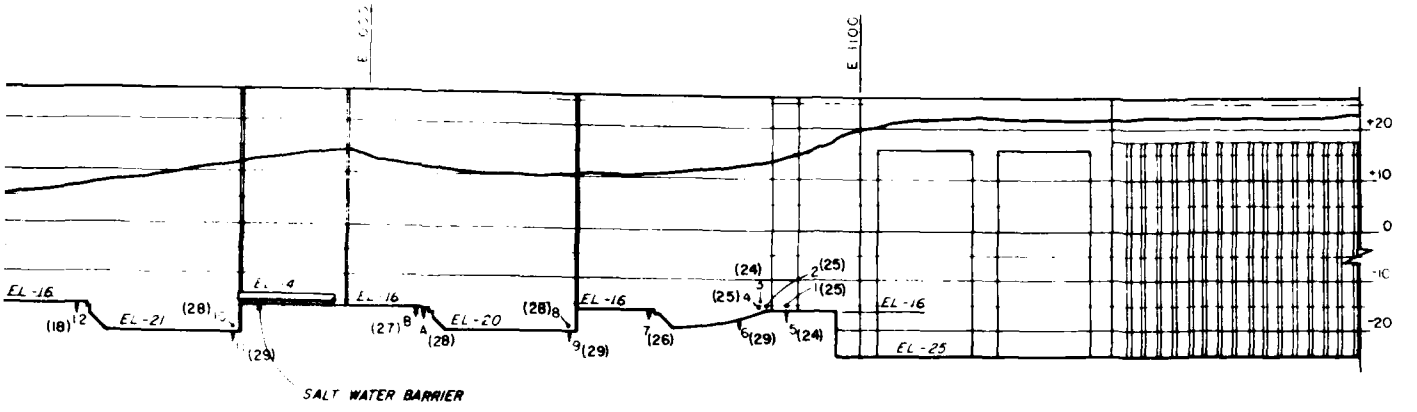

E 0
E 100
+10
0
-10
-20
EL -34
EL -29
20 (32)
EL -34
21 (29)
EL -29
EL -34
(23) 19

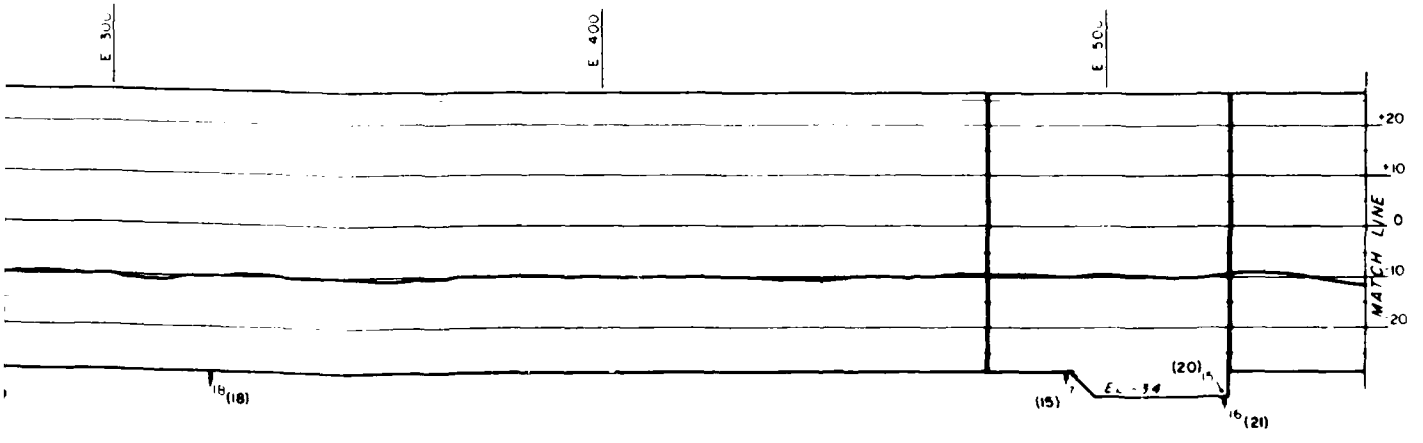


LEGEND

—— WATER-SURFACE PROFILE ALONG RIGHT WALL

(26) PRESSURE IN FEET OF WATER





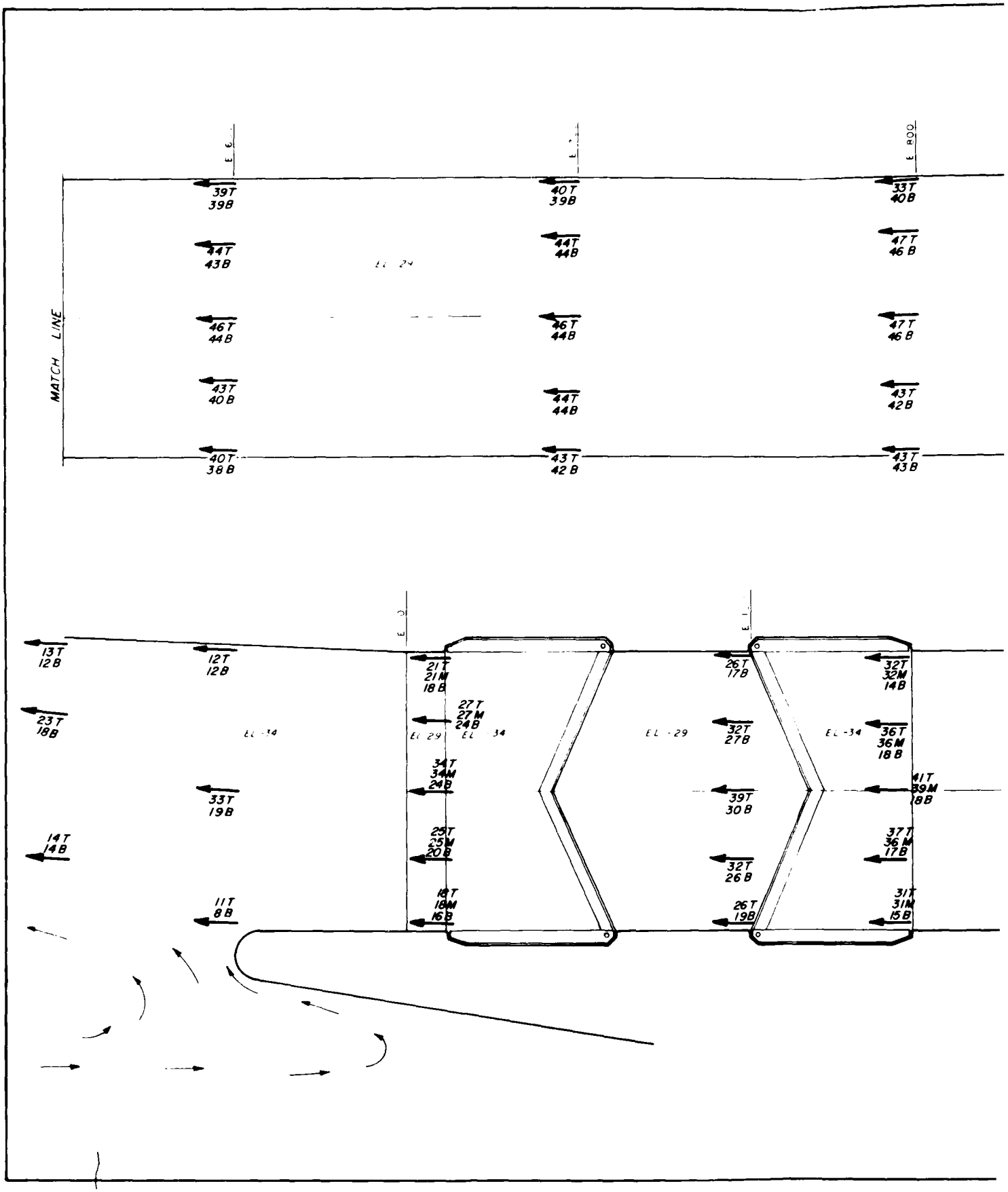
LOCK DISCHARGE 48 700 CFS

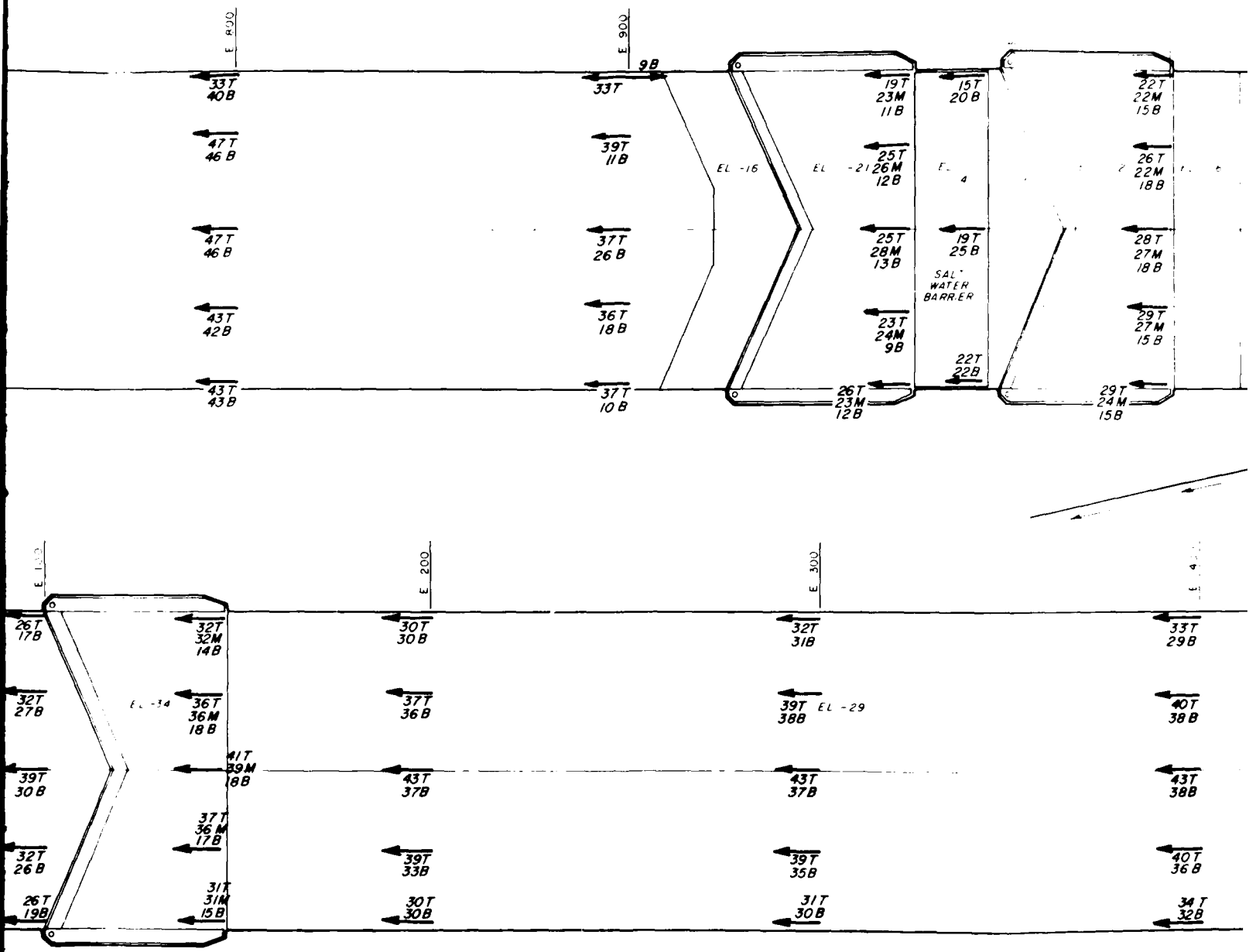
WATER SURFACE AND PRESSURES

FOREBAY EL 22; TAILWATER EL -2

FREE FLOW

PLATE 6


MATCH LINE
39T 39B
40T 39B
33T 40B
44T 43B
44T 44B
47T 46B
46T 44B
46T 44B
47T 46B
43T 40B
44T 44B
43T 42B
40T 38B
43T 42B
43T 43B
13T 12B
12T 12B
21T 21M 18B
27T 27M 24B
26T 17B
32T 32M 14B
23T 18B
32T 27B
36T 36M 18B
34T 34M 24B
41T 39M 18B
33T 19B
39T 30B
25T 25M 20B
37T 36M 17B
14T 14B
32T 26B
19T 18M 16B
31T 31M 15B
11T 8B
26T 19B



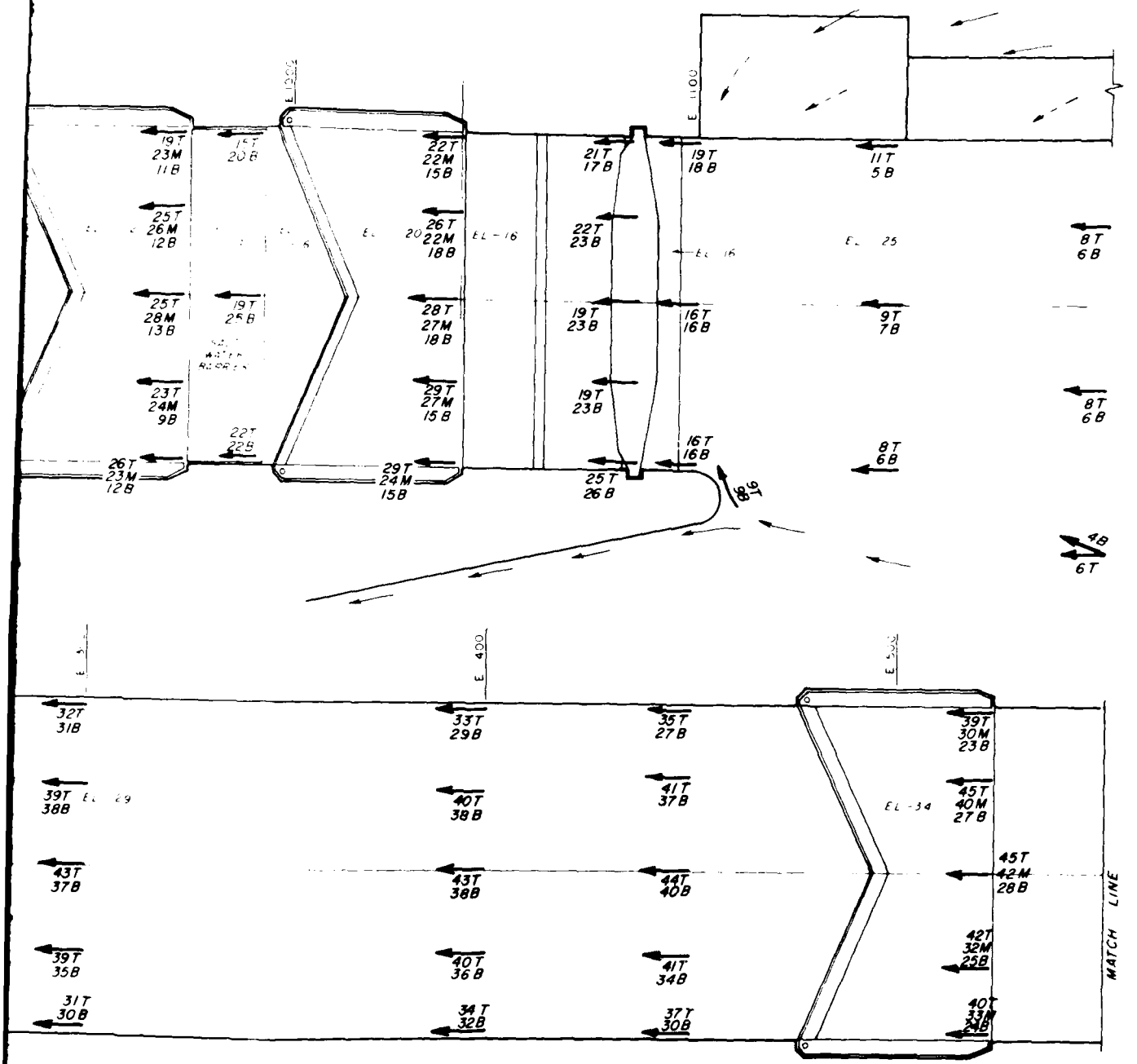
LEGEND

4 VELOCITY IN FPS

T 5-FT DEPTH

M MID-DEPTH

B 5 FT ABOVE BOTTOM



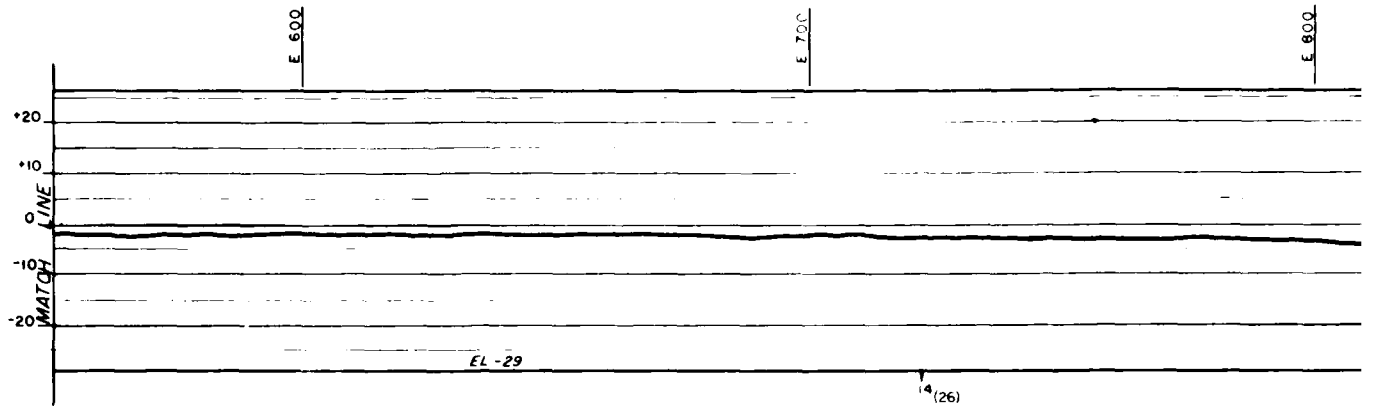
LOCK DISCHARGE 48 700 CFS

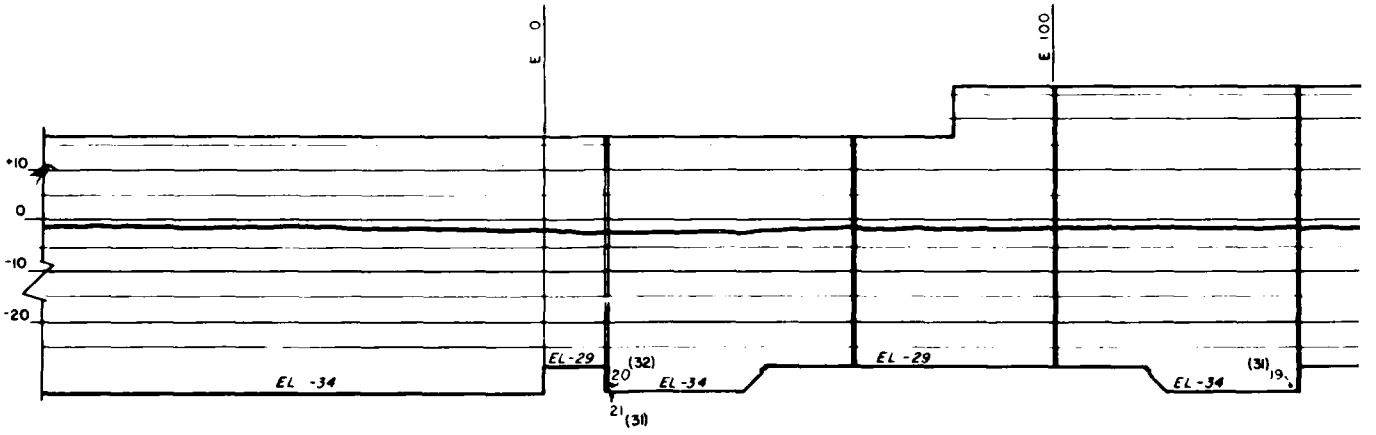
VELOCITIES

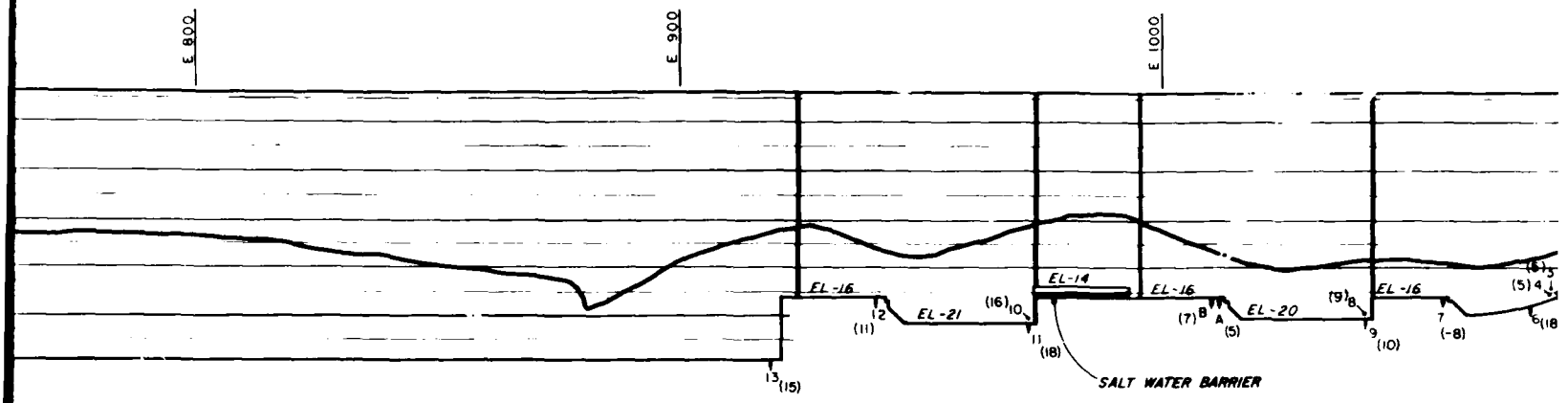
FOREBAY EL 22; TAILWATER EL -2
FREE FLOW

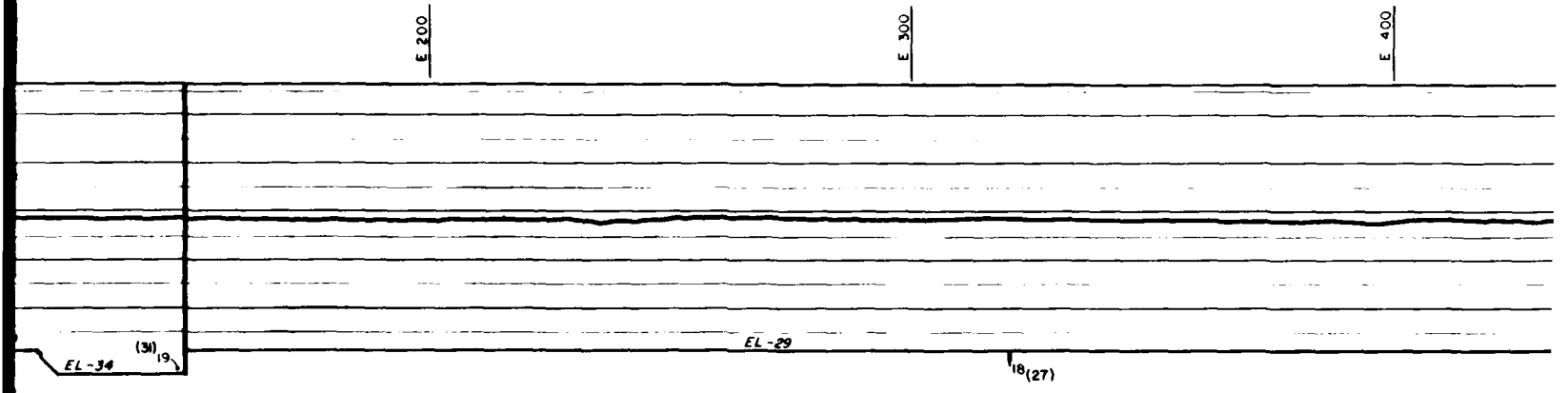
3

PLATE 7


E 600
E 700
E 800
+20
+10
0 LINE
-10
MATCH
-20
EL -29
14
(26)


E 0
E 100
+10
0
-10
-20
EL -34
EL -29
20
(32)
EL -34
EL -29
(31)
19
EL -34
21
(31)

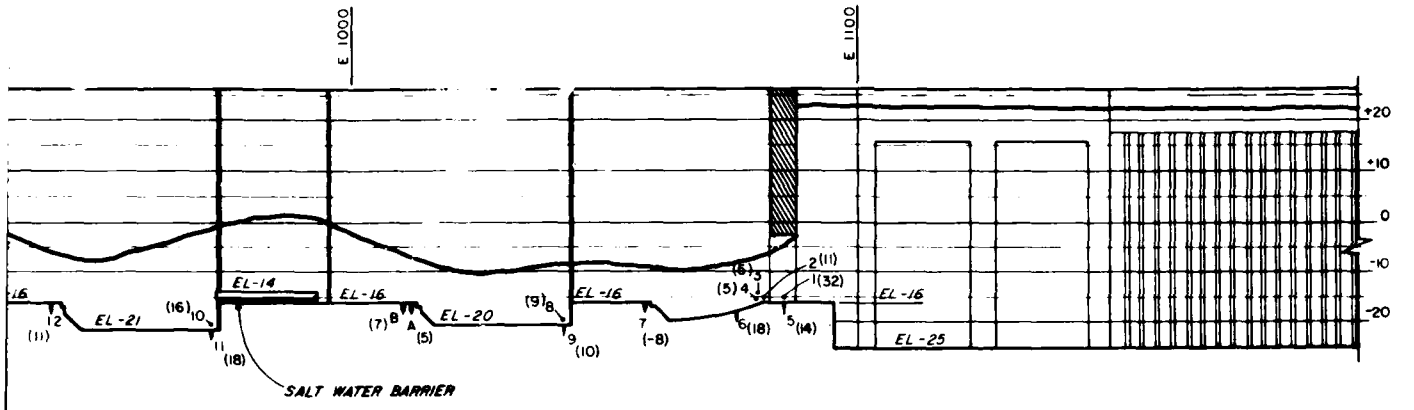


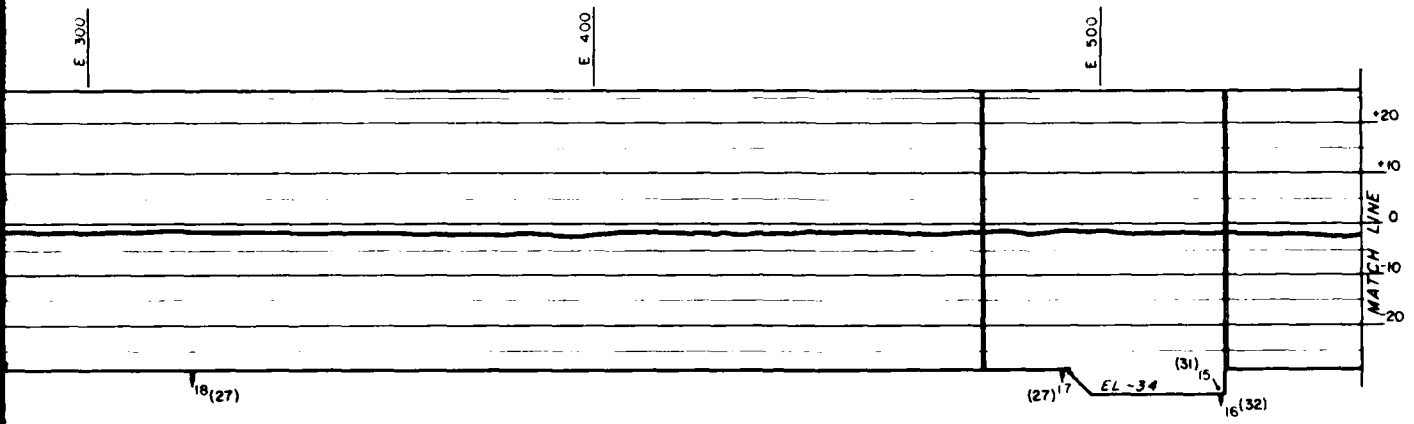


LEGEND

—— WATER-SURFACE PROFILE ALONG RIGHT WALL

(26) PRESSURE IN FEET OF WATER





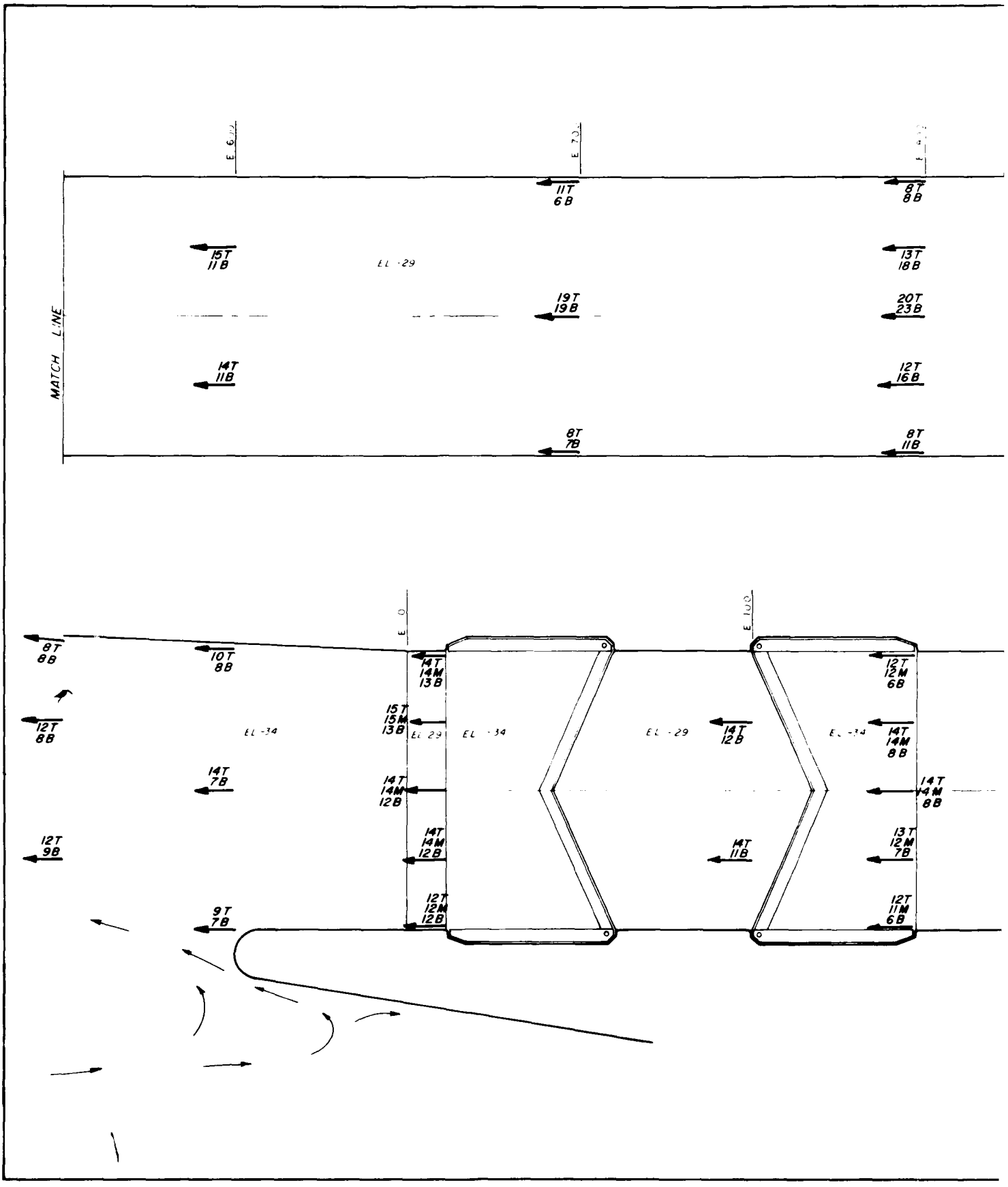
LOCK DISCHARGE 27 860 CFS

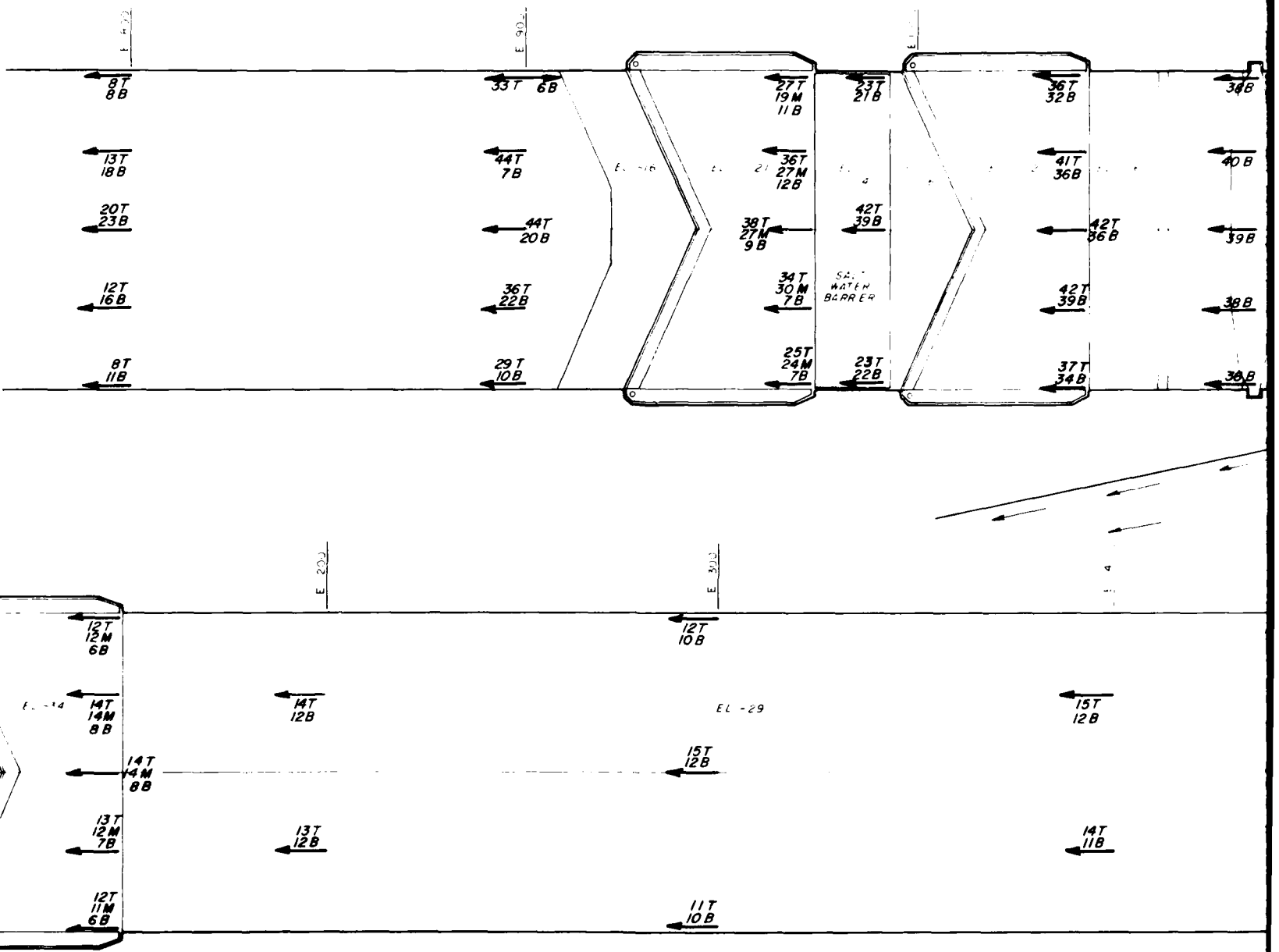
WATER SURFACE AND PRESSURES

FOREBAY EL 22; TAILWATER EL -2

BULKHEAD OPEN 13 FT

PLATE 8


MATCH LINE
EL -29
11T
6B
8T
8B
15T
11B
13T
18B
19T
19B
20T
23B
14T
11B
12T
16B
8T
7B
8T
11B
EL -34
EL -29
EL -34
EL -29
EL -34
8T
8B
10T
8B
12T
8B
14T
7B
12T
9B
9T
7B
14T
14M
13B
15T
15M
13B
14T
14M
12B
14T
14M
12B
12T
12M
12B
14T
12B
14T
11B
12T
12M
6B
14T
14M
8B
14T
14M
8B
13T
12M
7B
12T
11M
6B



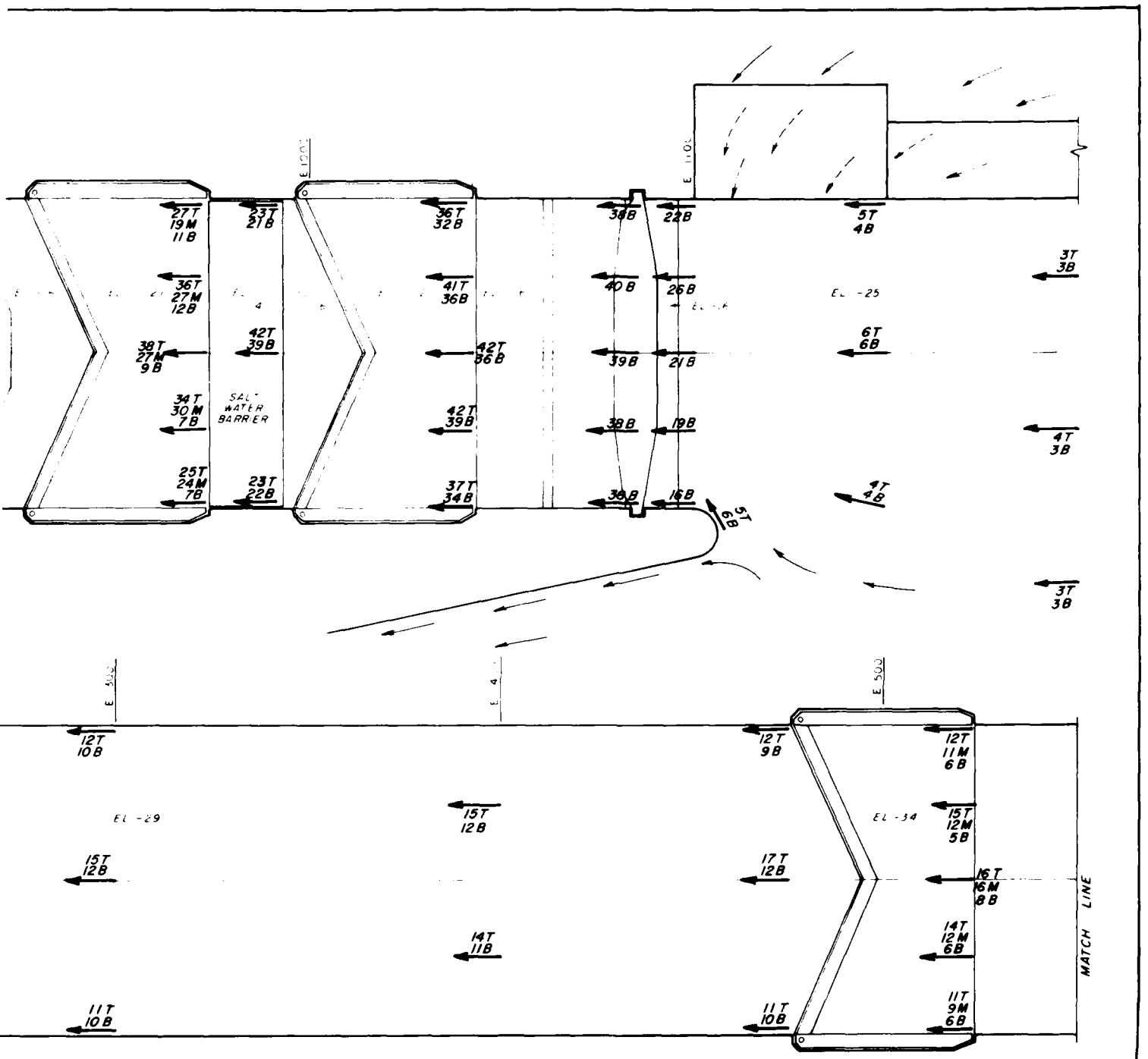
LEGEND

4 ← VELOCITY IN FPS

T 5-FT DEPTH

M . MID-DEPTH

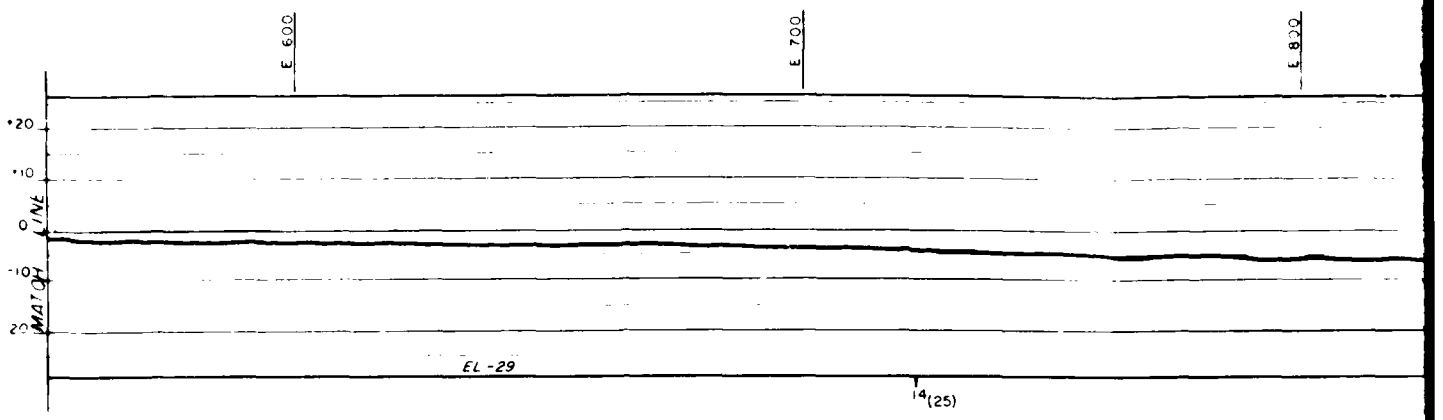
B 5 FT ABOVE BOTTOM

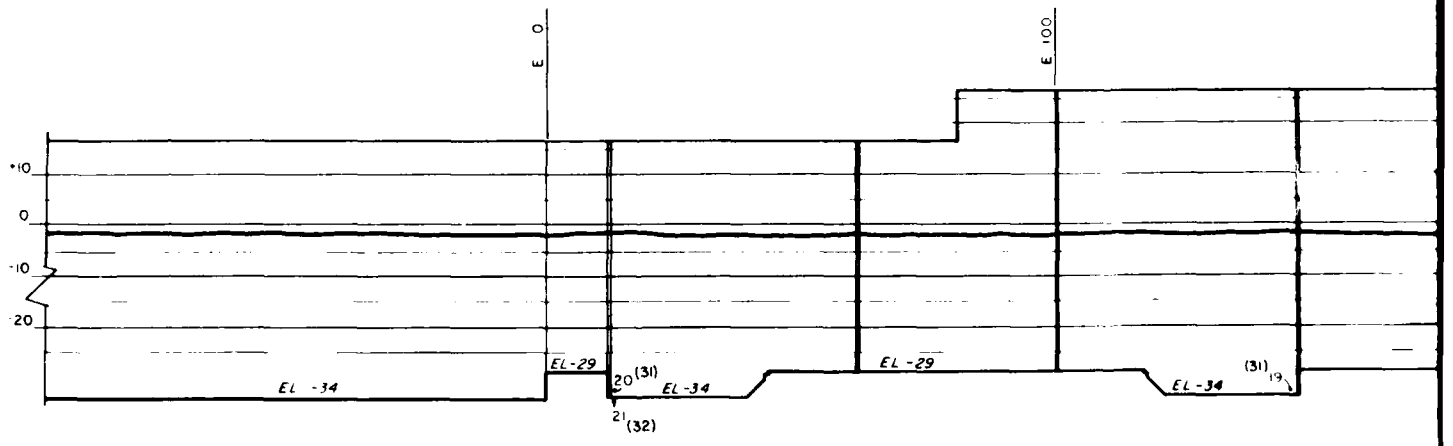


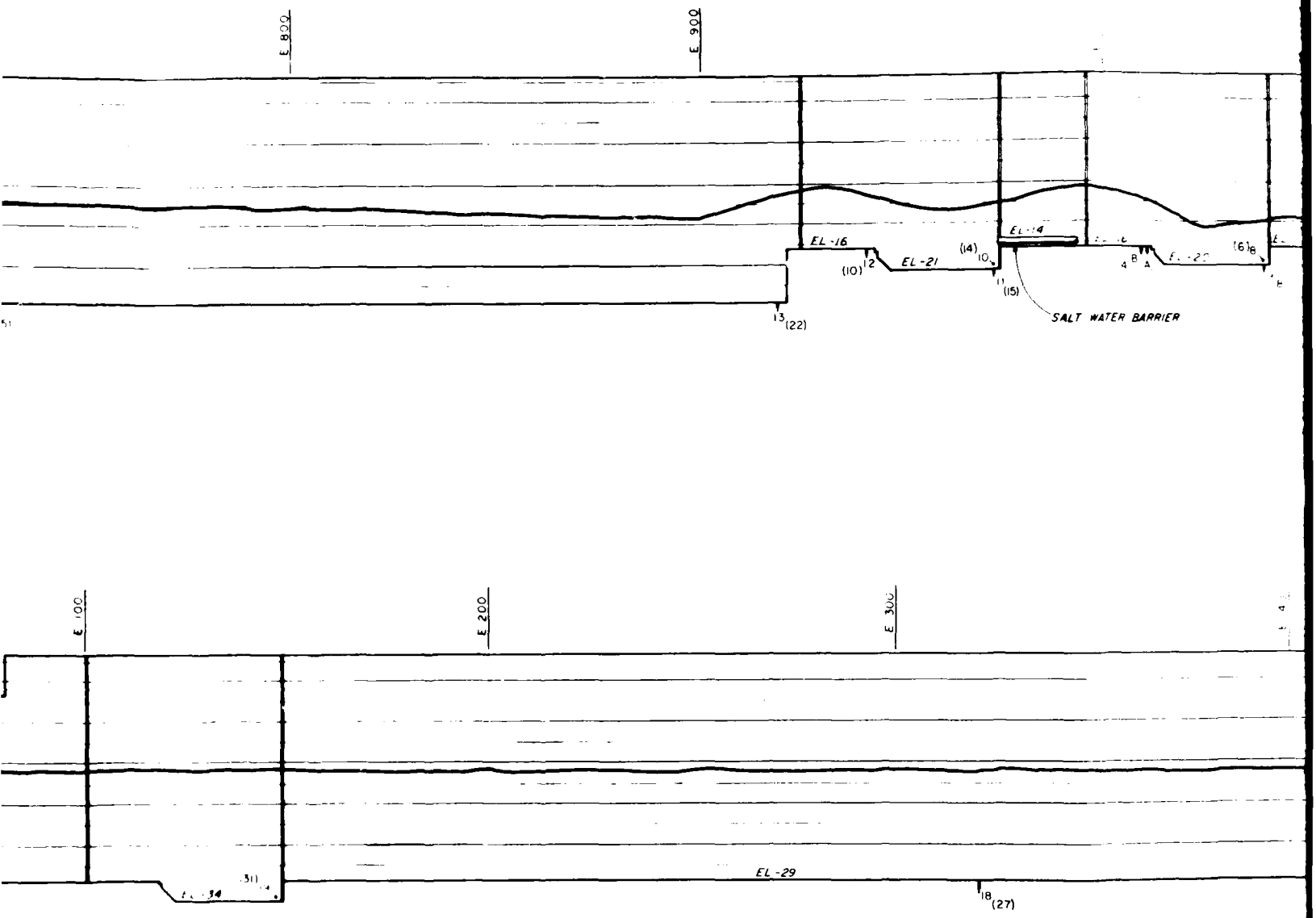
LOCK DISCHARGE 27 860 CFS

VELOCITIES

FOREBAY EL 22; TAILWATER EL -2
BULKHEAD OPEN 13 FT


E 600
E 700
E 800
+20
+10
0
-10
-20
MATCH LINE
EL -29
14 (25)

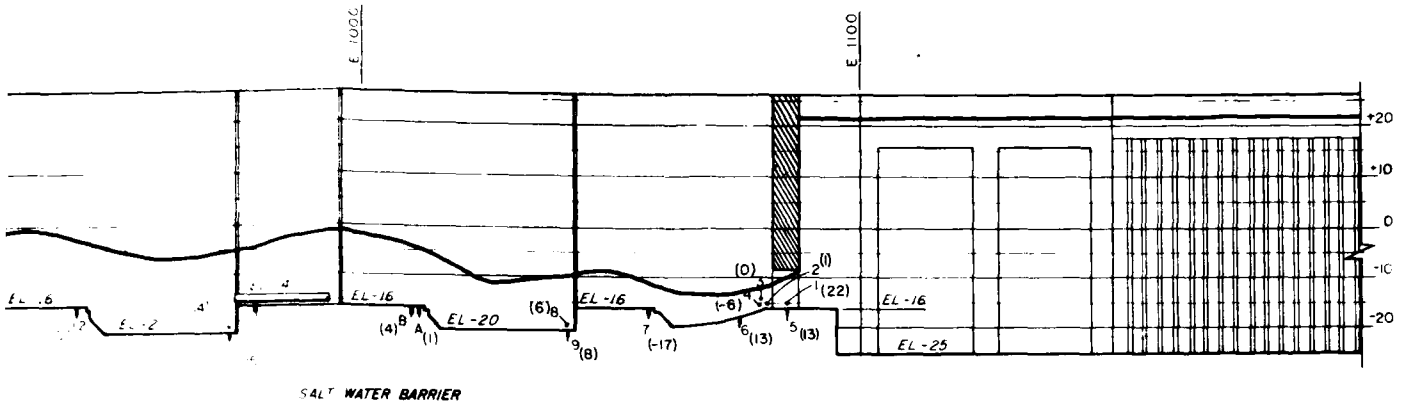

E 0
E 100
+10
0
-10
-20
EL -34
EL -29
20 (31)
EL -34
EL -29
EL -34
(31) 19
21 (32)



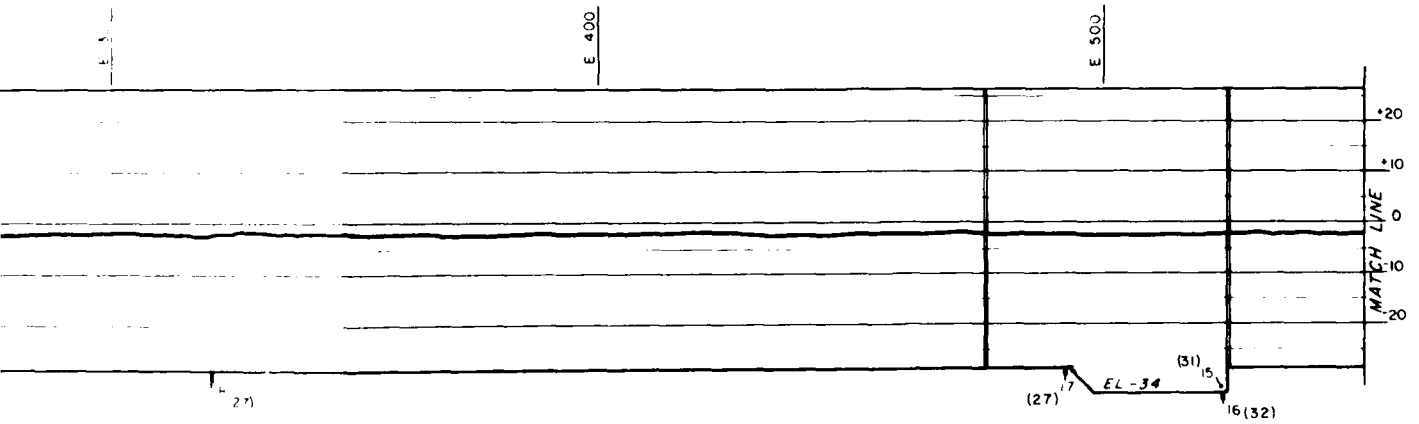
LEGEND

—— WATER-SURFACE PROFILE ALONG RIGHT WALL

(26) PRESSURE IN FEET OF WATER



SALT WATER BARRIER



LOCK DISCHARGE 18 330 CFS

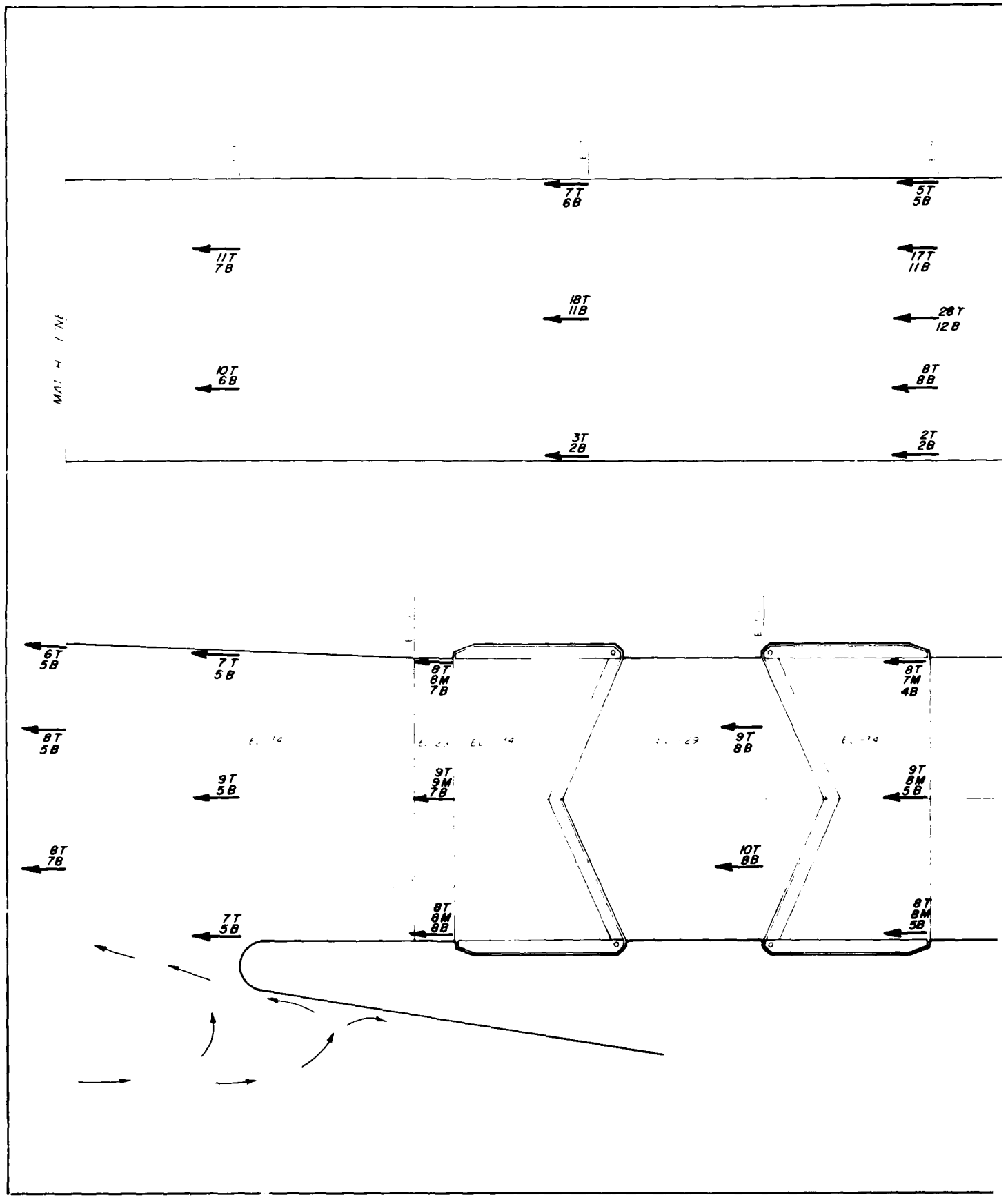
WATER SURFACE AND PRESSURES

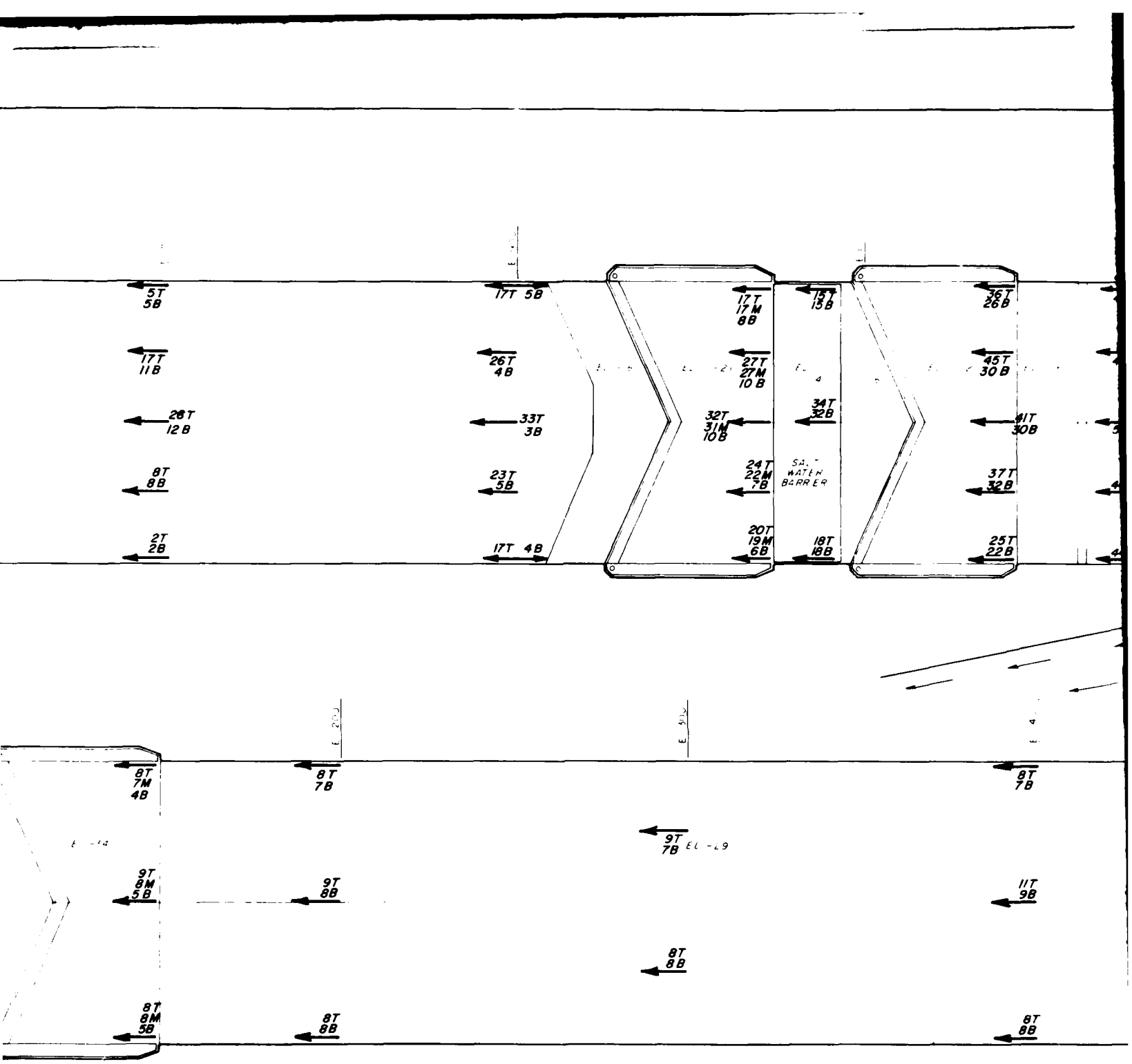
FOREBAY EL 22; TAILWATER EL -2

BULKHEAD OPEN 8 FT

3

PLATE 10


7T
6B
5T
5B
11T
7B
17T
11B
18T
11B
26T
12B
10T
6B
8T
8B
3T
2B
2T
2B
6T
5B
7T
5B
8T
8M
7B
8T
7M
4B
8T
5B
9T
8B
9T
5B
9T
9M
7B
9T
9M
5B
8T
7B
10T
8B
7T
5B
8T
8M
8B
8T
8M
5B



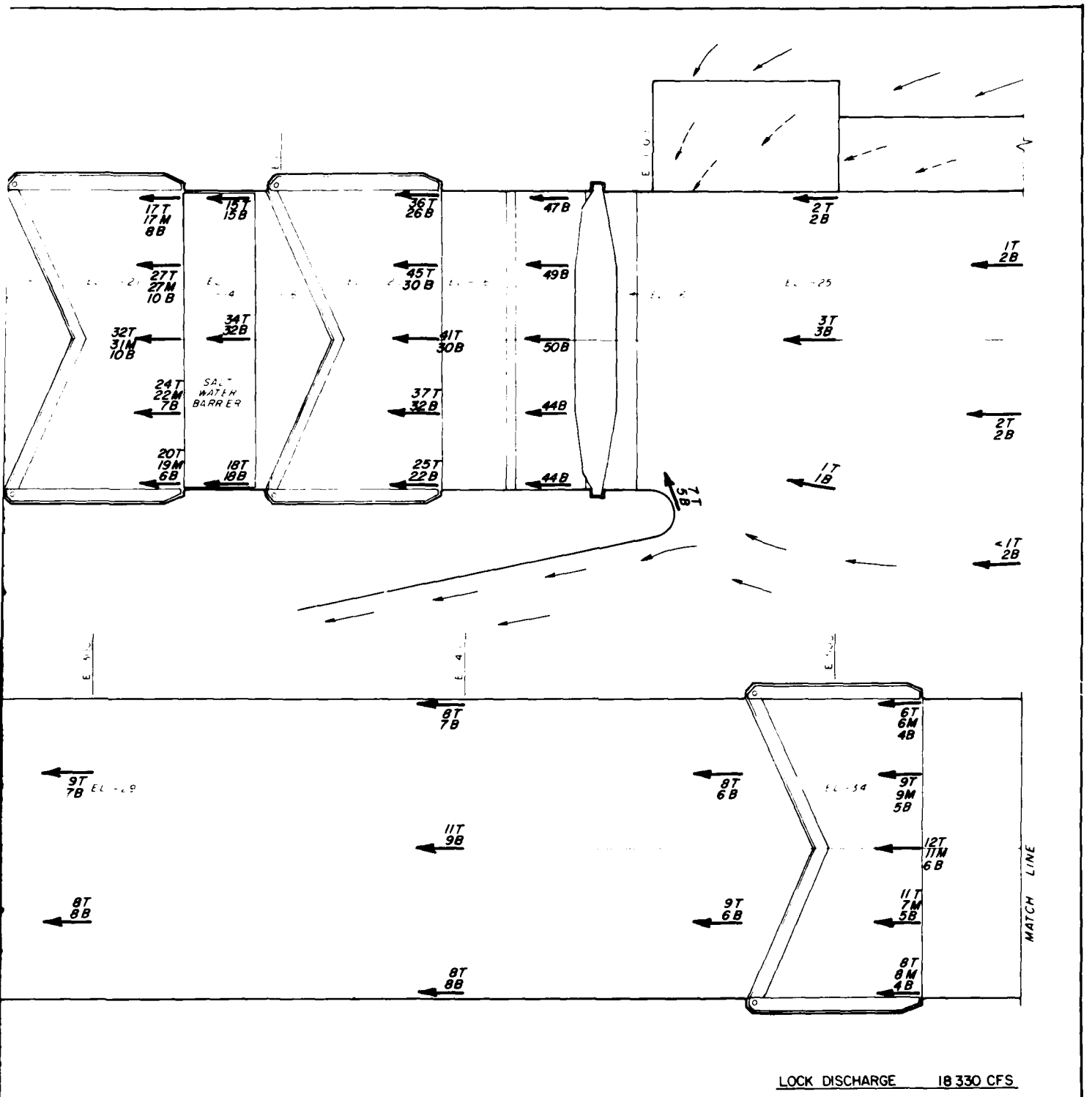
LEGEND

4 VELOCITY IN FPS

T 5-FT DEPTH

M MID-DEPTH

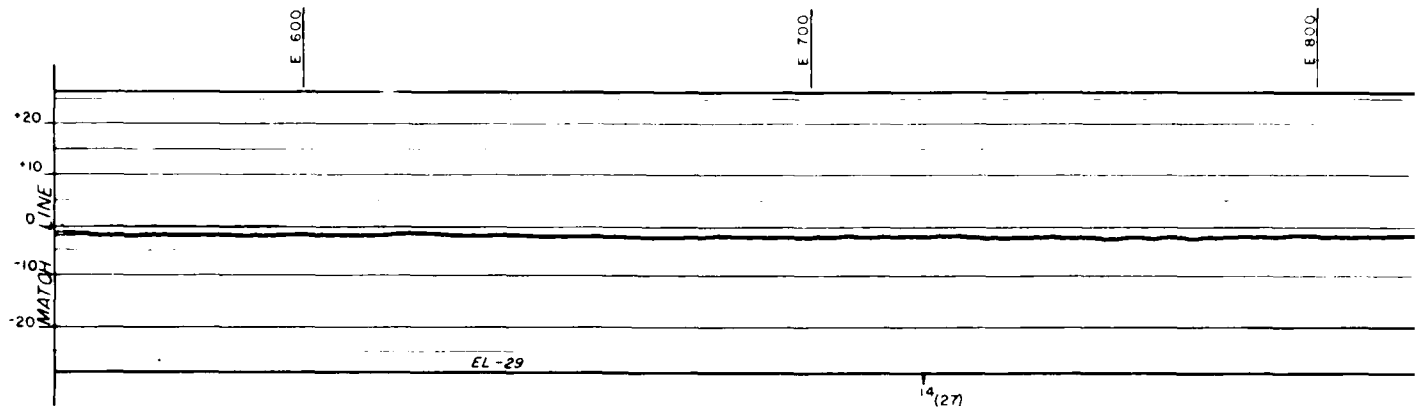
B 5 FT ABOVE BOTTOM

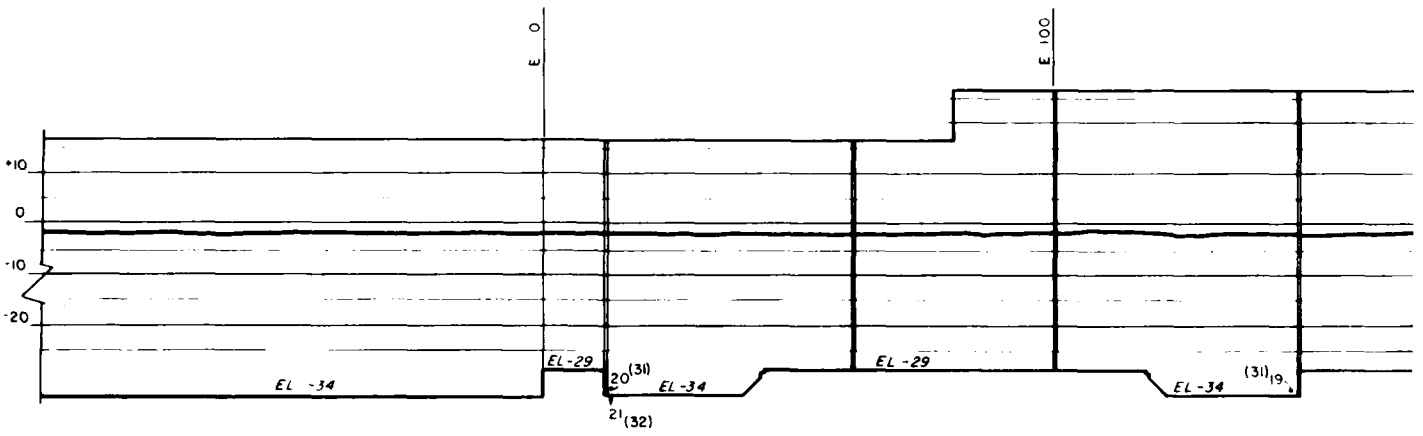


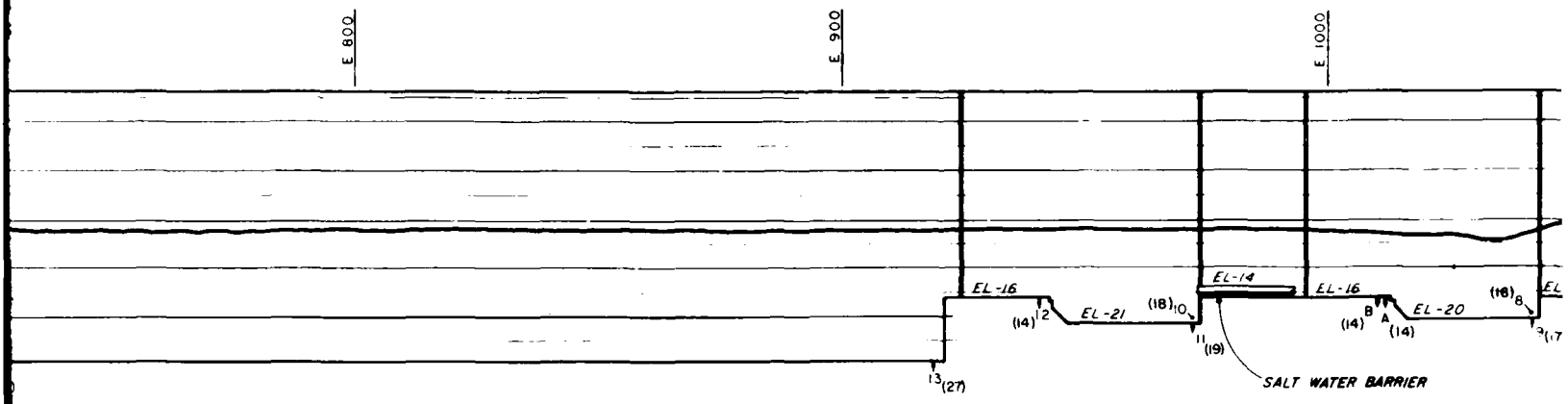
LOCK DISCHARGE 18 330 CFS

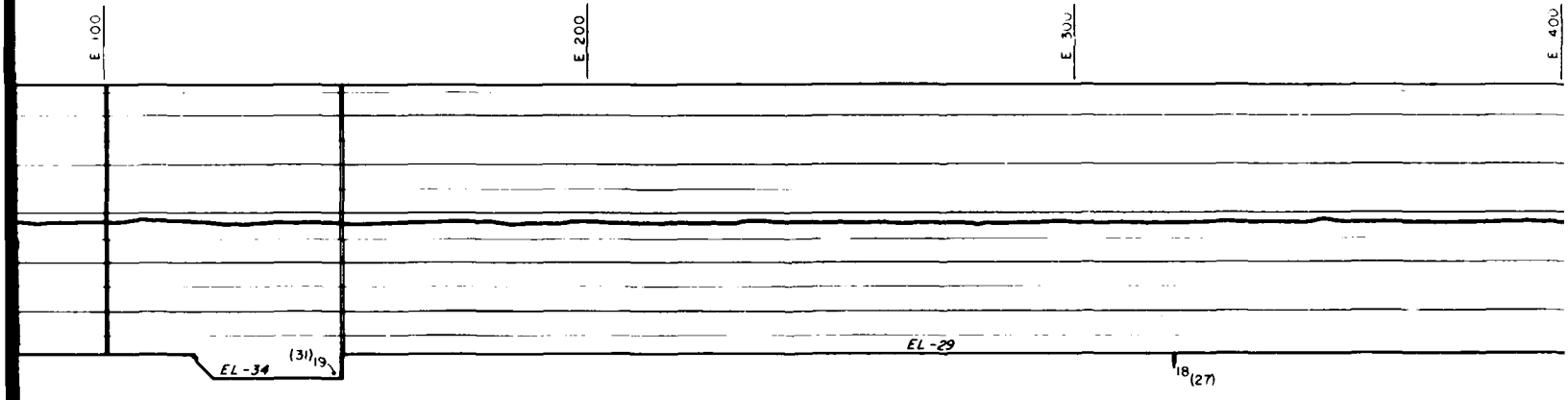
VELOCITIES

FOREBAY EL 22; TAILWATER EL -2
BULKHEAD OPEN 8 FT


E 600
E 700
E 800
+20
+10
0
-10
-20
MATCH LINE
EL -29
14(27)


E 0
E 100
+10
0
-10
-20
EL -34
EL -29
20(31)
EL -34
21(32)
EL -29
EL -34
(31)19

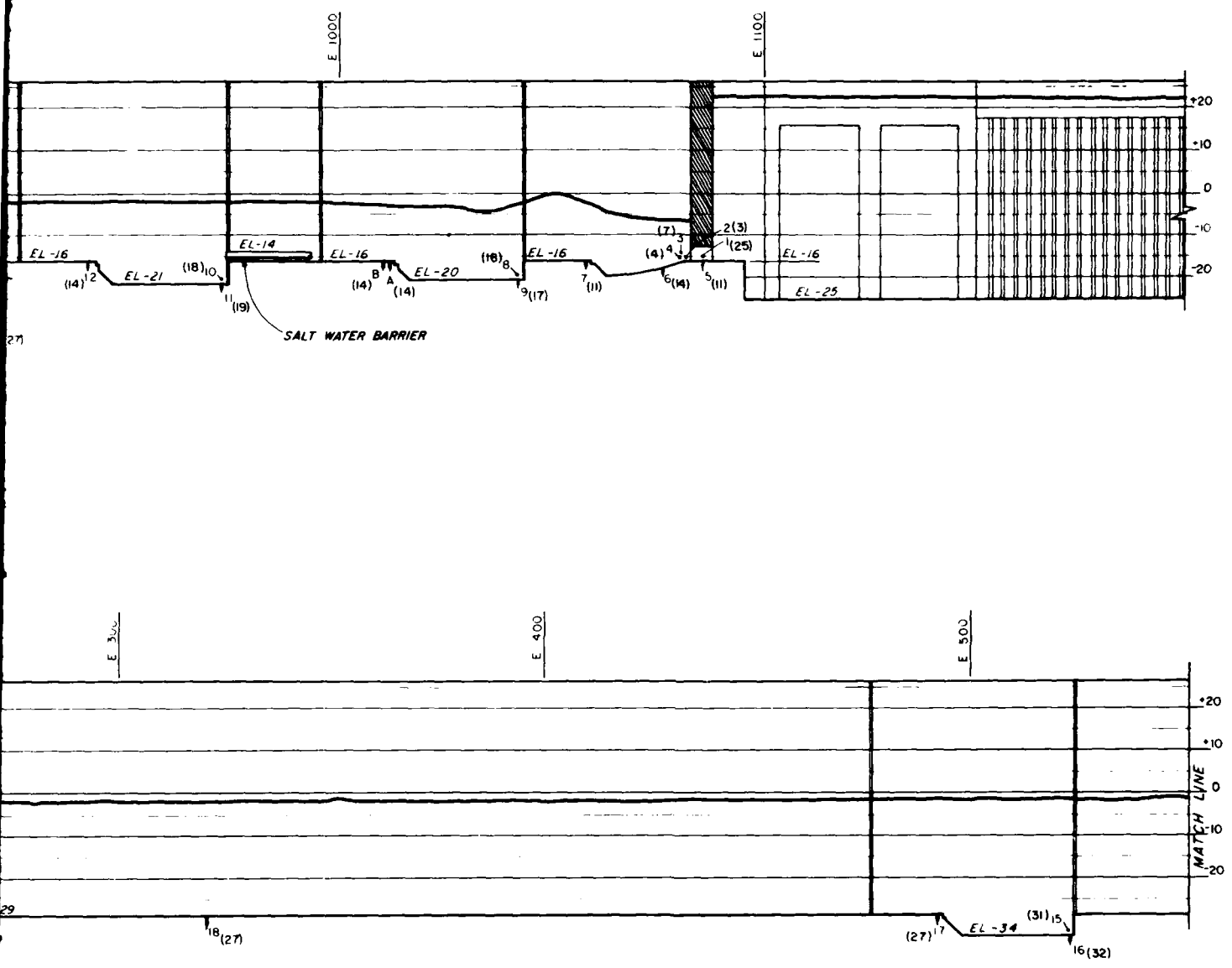




LEGEND

—— WATER-SURFACE PROFILE ALONG RIGHT WALL

(26) PRESSURE IN FEET OF WATER



LOCK DISCHARGE 6 430 CFS

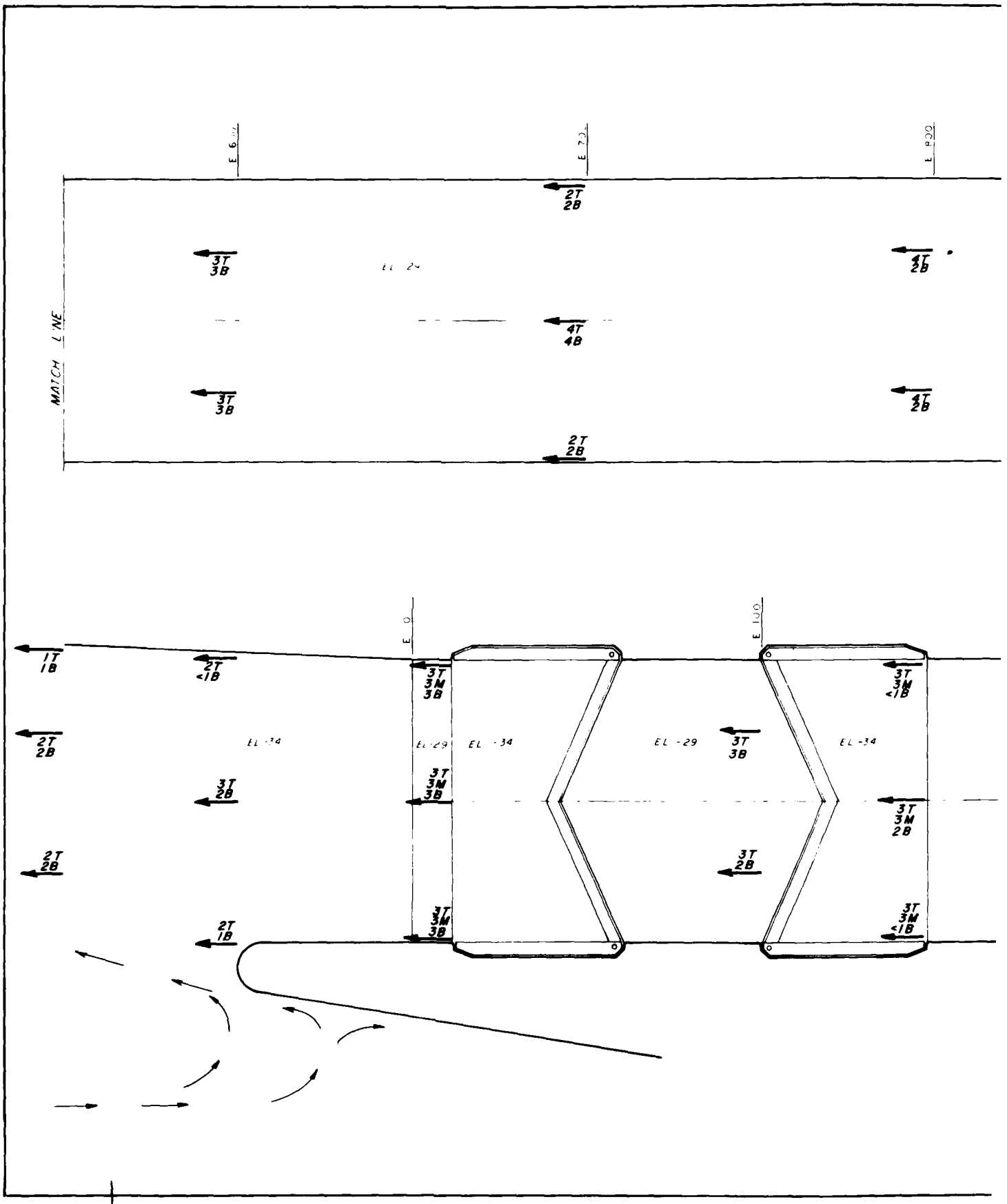
WATER SURFACE AND PRESSURES

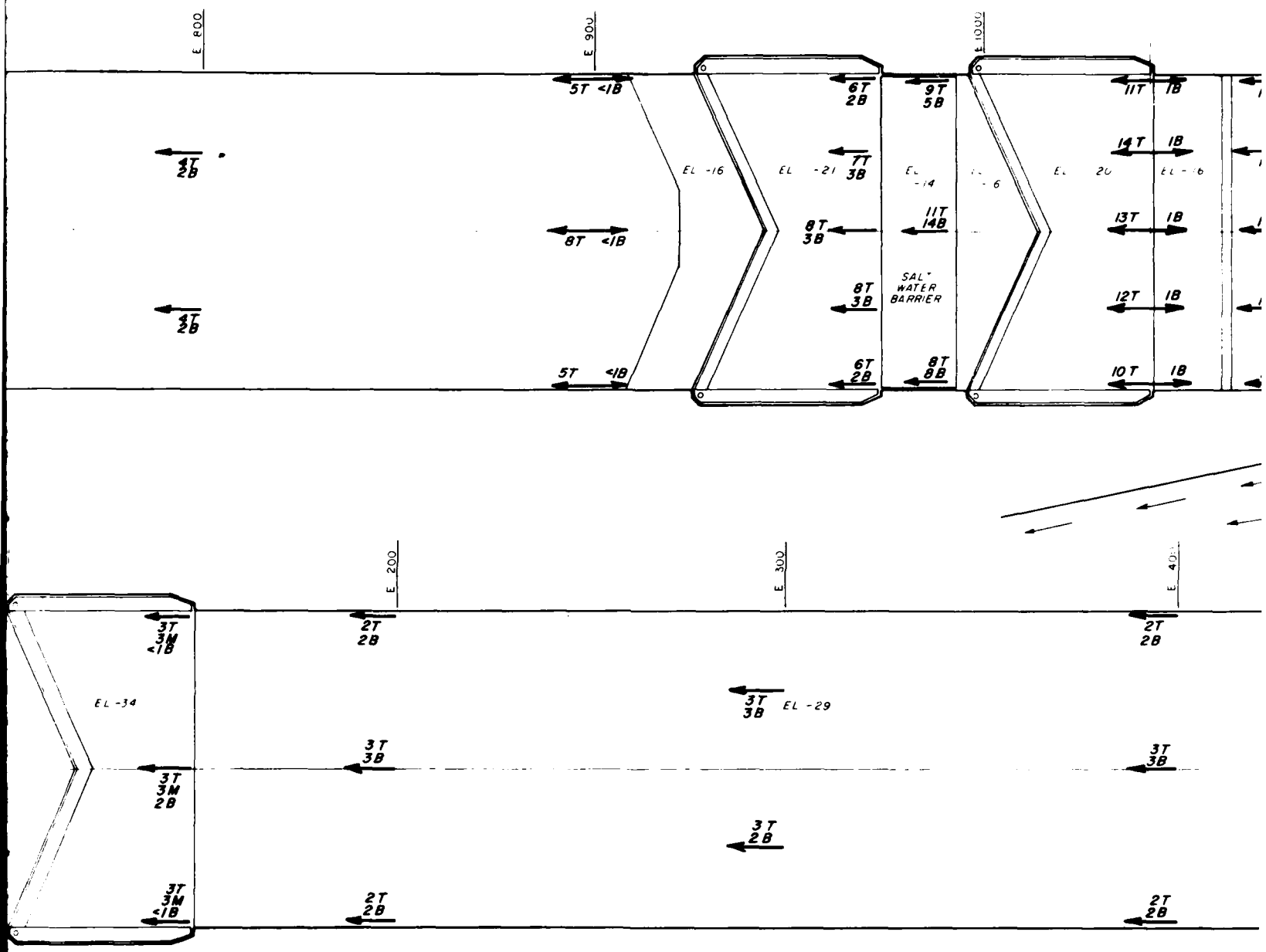
FOREBAY EL 22; TAILWATER EL -2

BULKHEAD OPEN 3 FT

3

PLATE 12


E 70
2T
2B
3T
3B
EL -24
4T
4B
MATCH LINE
2T
2B
E 0
E 100
1T
1B
2T
<1B
3T
3M
3B
EL -34
EL -29
EL -34
EL -29
3T
3B
EL -34
3T
3M
2B
3T
2B
3T
3M
<1B



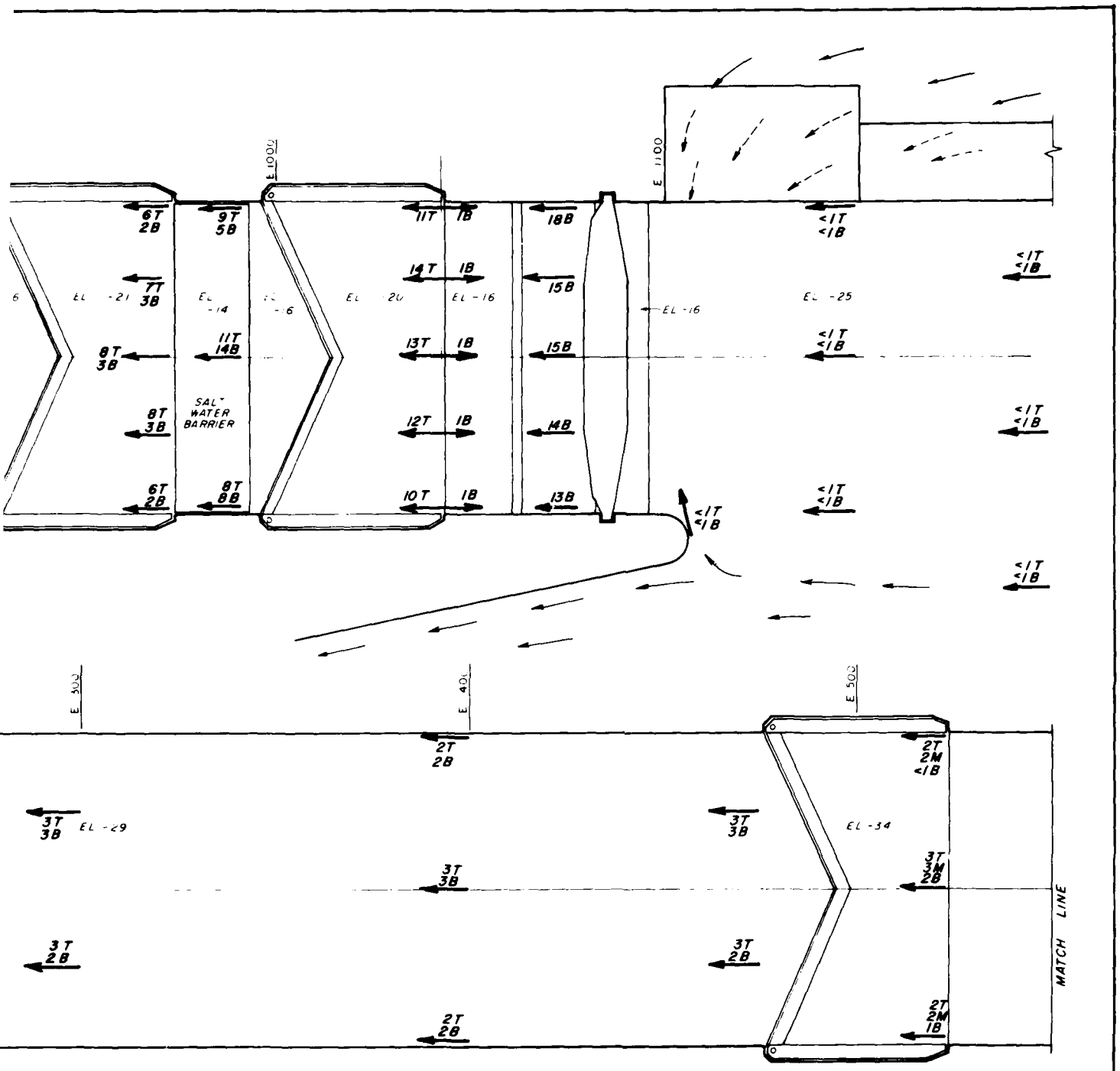
LEGEND

4 ← VELOCITY IN FPS

T 5-FT DEPTH

M MID-DEPTH

B 5 FT ABOVE BOTTOM

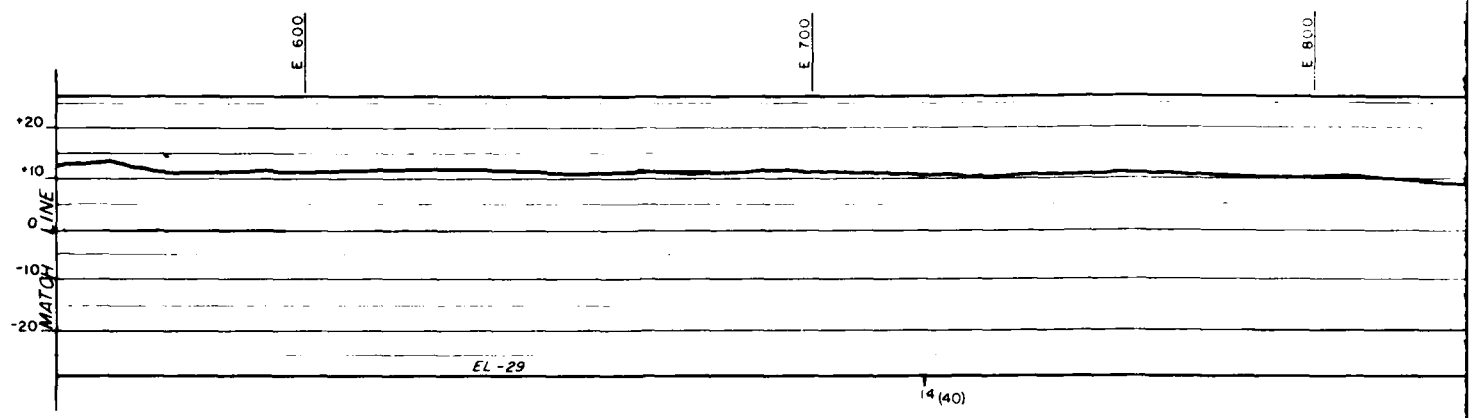


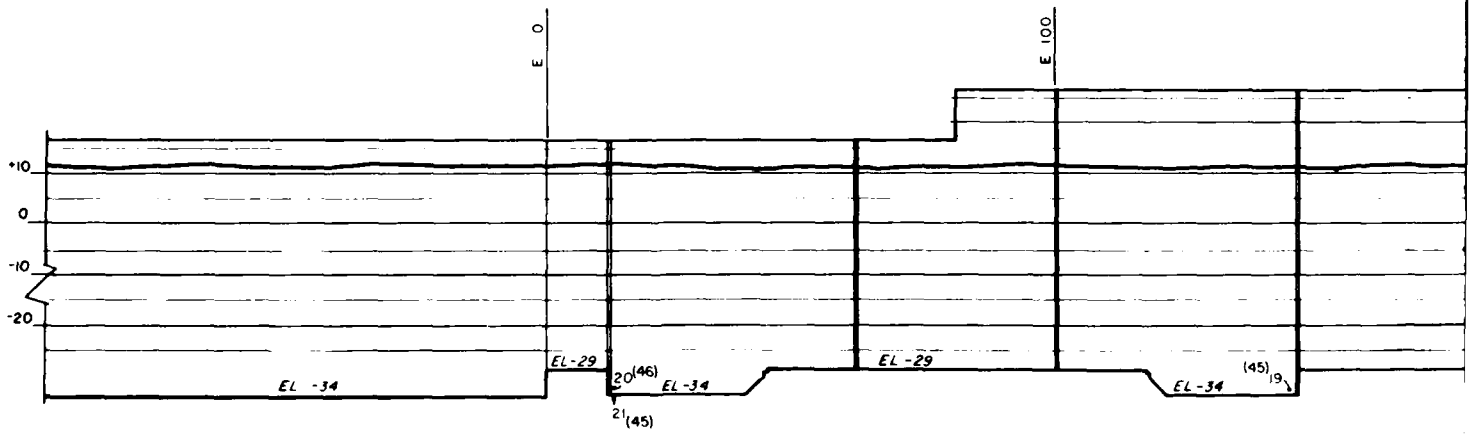
VELOCITIES

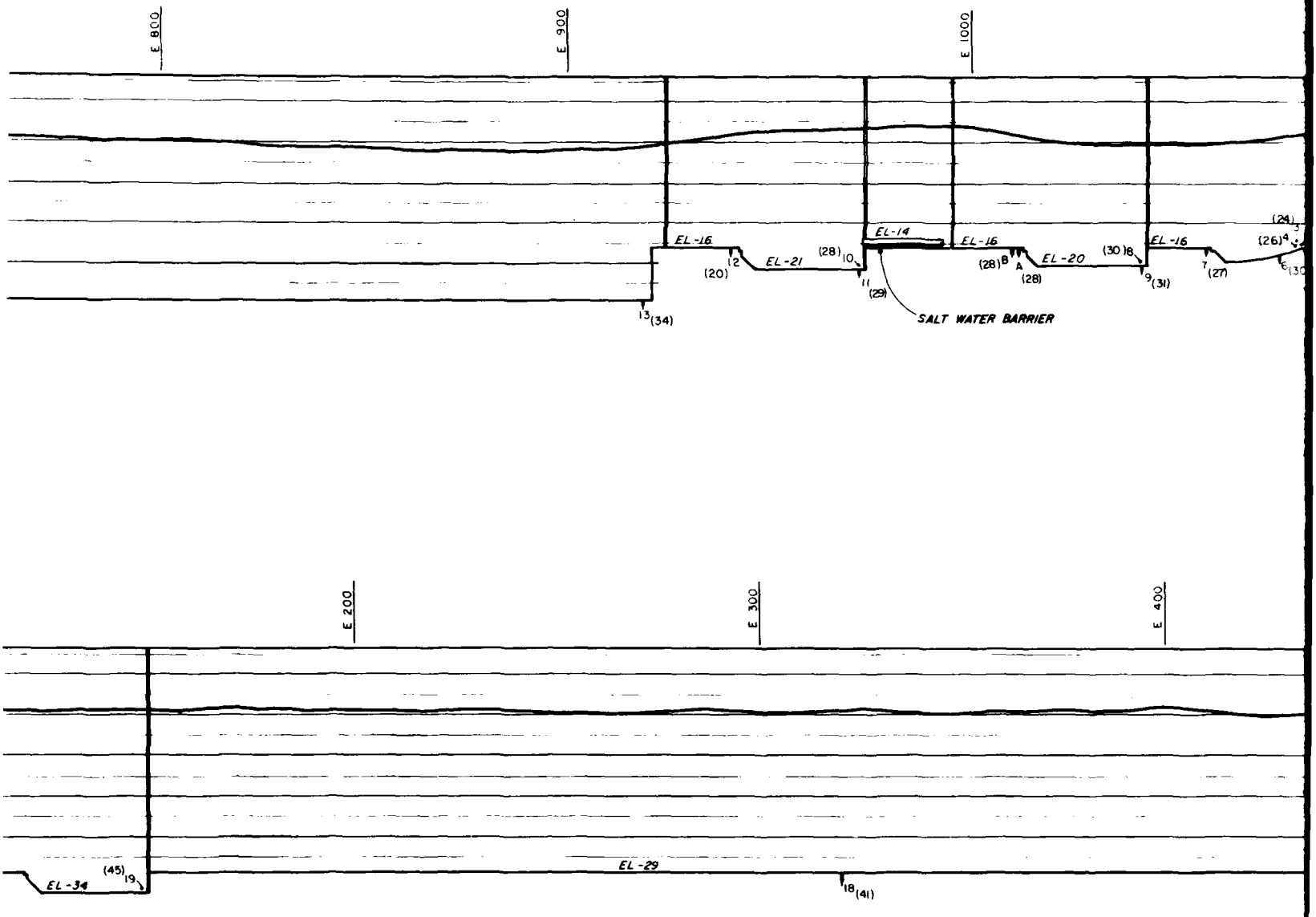
FOREBAY EL 22; TAILWATER EL -2
BULKHEAD OPEN 3 FT

3

PLATE 13


E 600
E 700
E 800
+20
+10
0 LINE
-10
MATCH
-20
EL -29
14 (40)

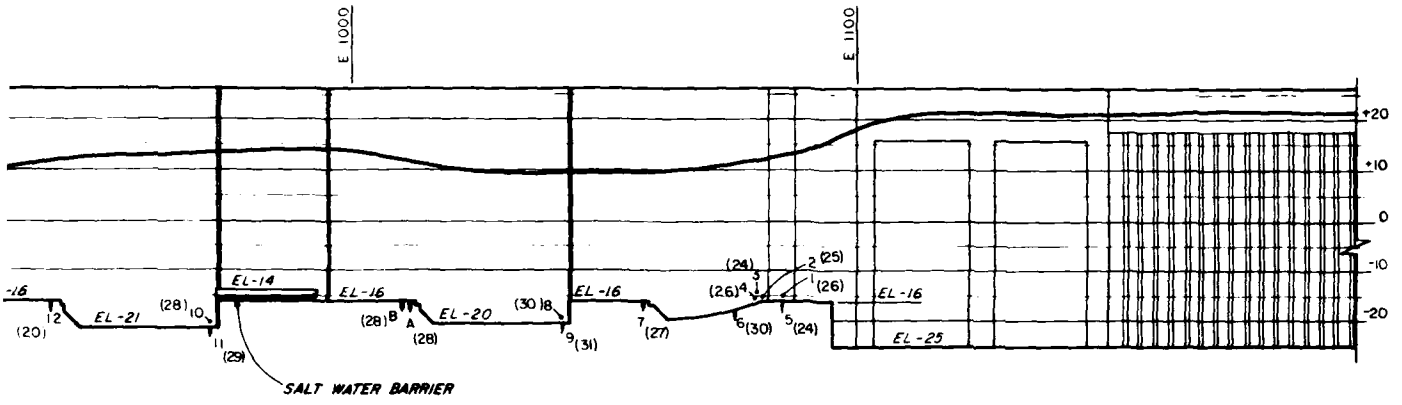

E 0
E 100
+10
0
-10
-20
EL -34
EL -29
20 (46)
EL -34
21 (45)
EL -29
EL -34
(45) 19

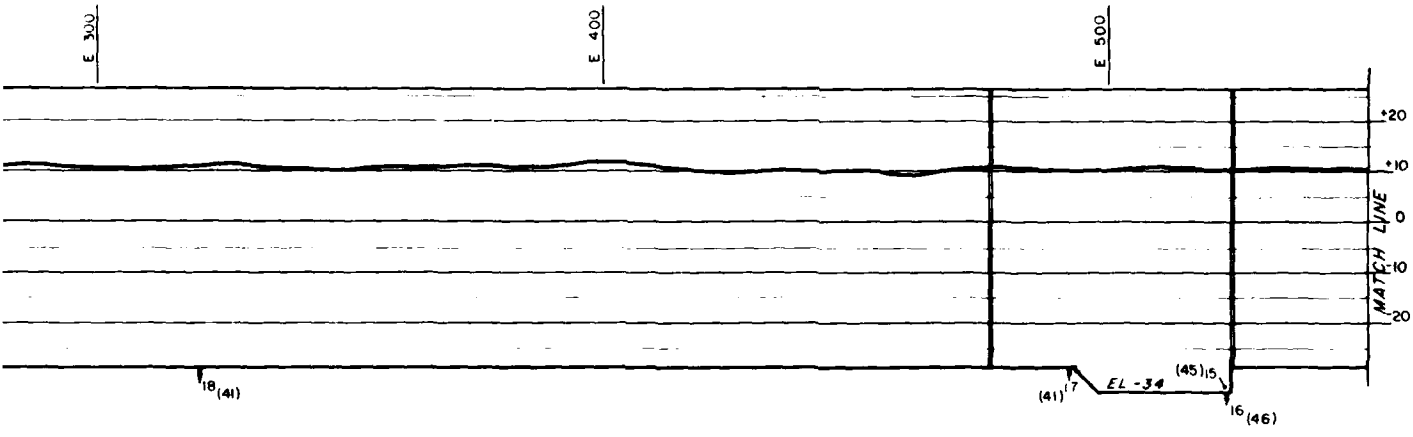


LEGEND

—— WATER-SURFACE PROFILE ALONG RIGHT WALL

(26) PRESSURE IN FEET OF WATER





LOCK DISCHARGE 48 700 CFS

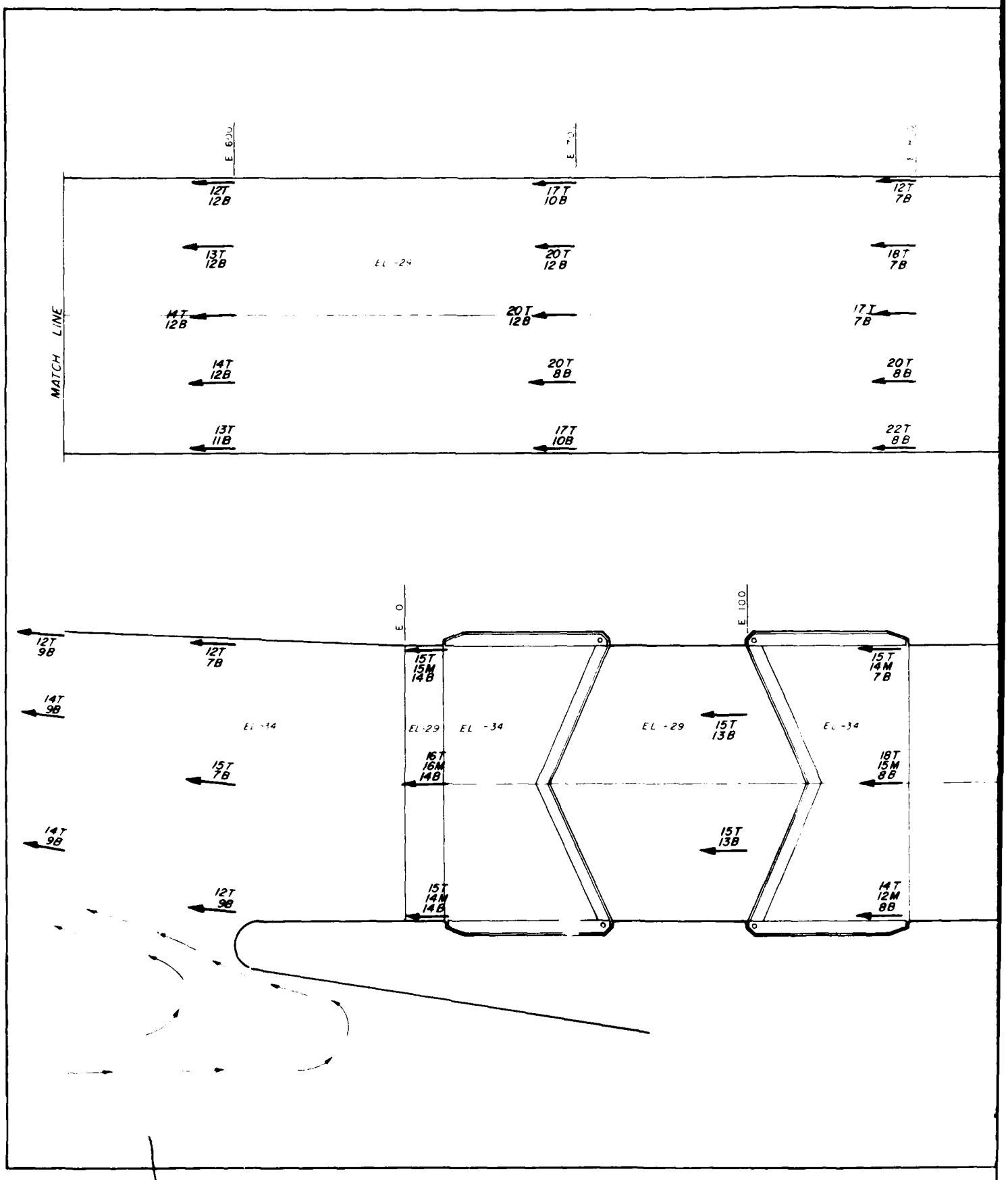
WATER SURFACE AND PRESSURES

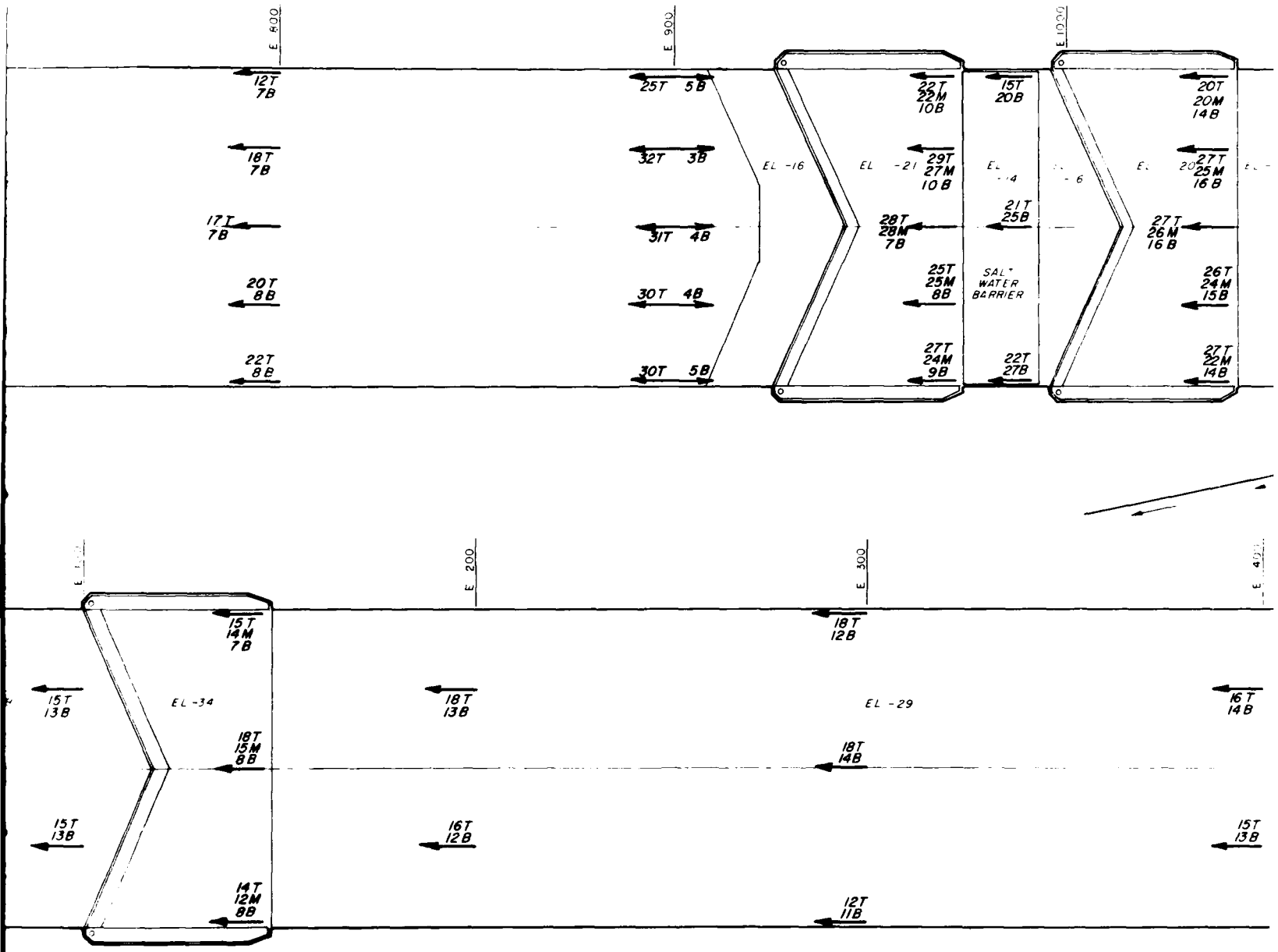
FOREBAY EL 22; TAILWATER EL +12

FREE FLOW

3

PLATE 14


E 600
12T 12B
13T 12B
14T 12B
14T 12B
13T 11B
EL -24
MATCH LINE
17T 10B
20T 12B
20T 12B
20T 8B
17T 10B
18T 7B
17T 7B
20T 8B
22T 8B
E 0
E 100
12T 9B
12T 7B
14T 9B
15T 7B
14T 9B
12T 9B
EL -34
EL -29
15T 15M 14B
16T 16M 14B
15T 14M 14B
EL -34
EL -29
15T 13B
15T 13B
EL -34
15T 14M 7B
18T 15M 8B
14T 12M 8B



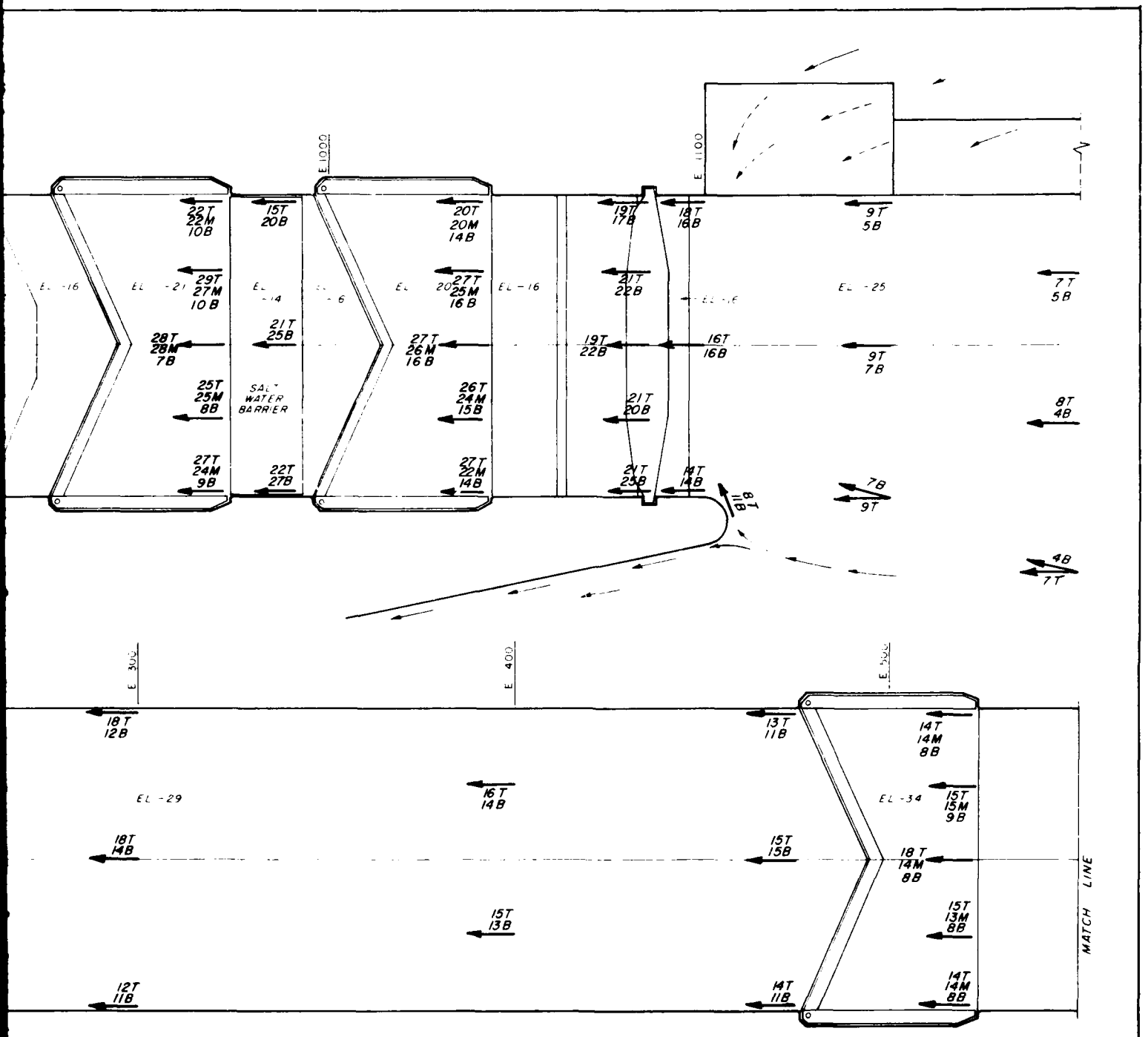
LEGEND

4 ← VELOCITY IN FPS

T 5-FT DEPTH

M MID-DEPTH

B 5 FT ABOVE BOTTOM

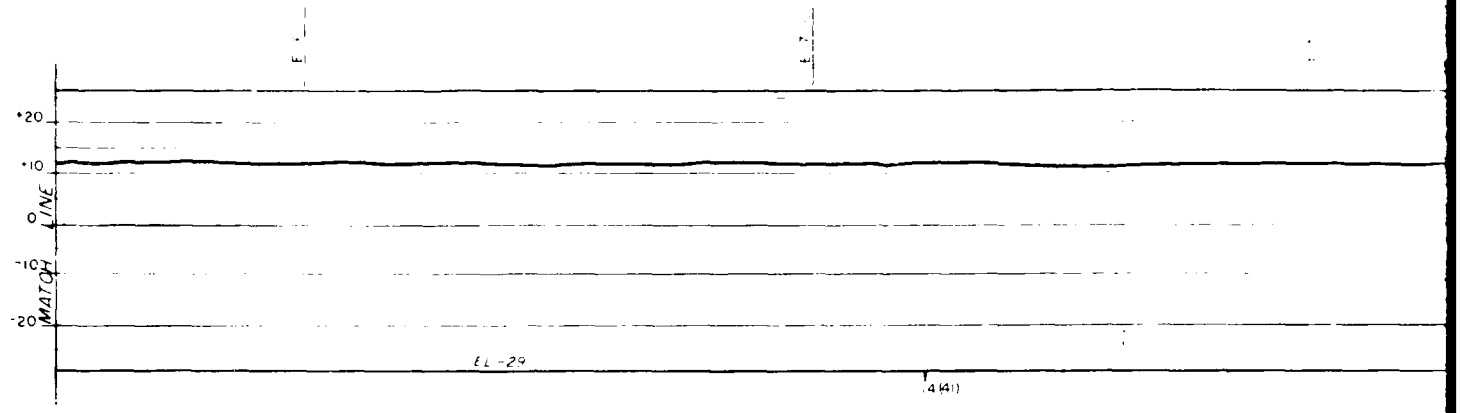


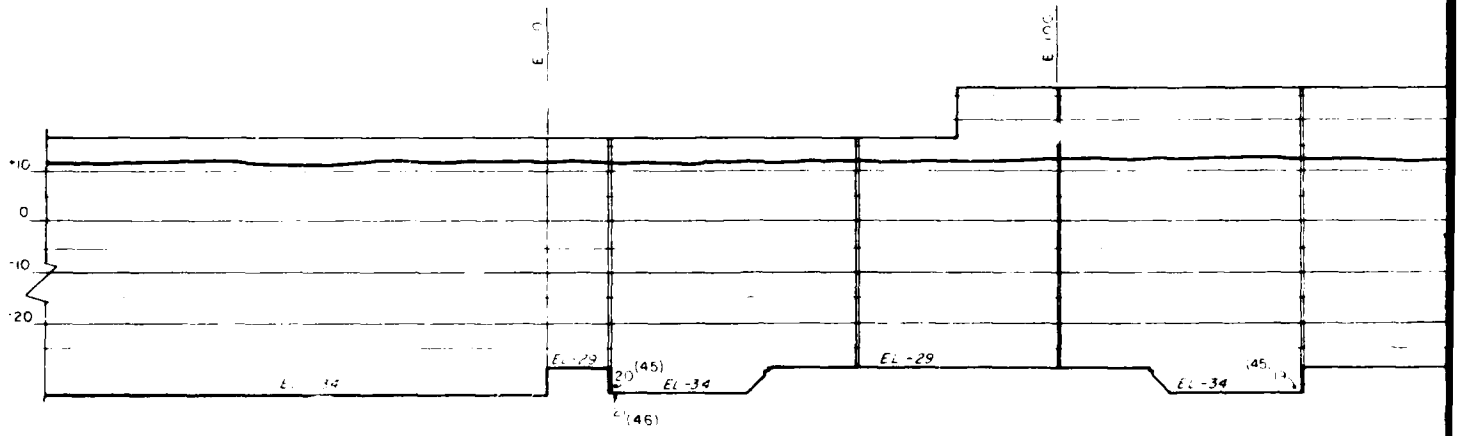
LOCK DISCHARGE 48 700 CFS

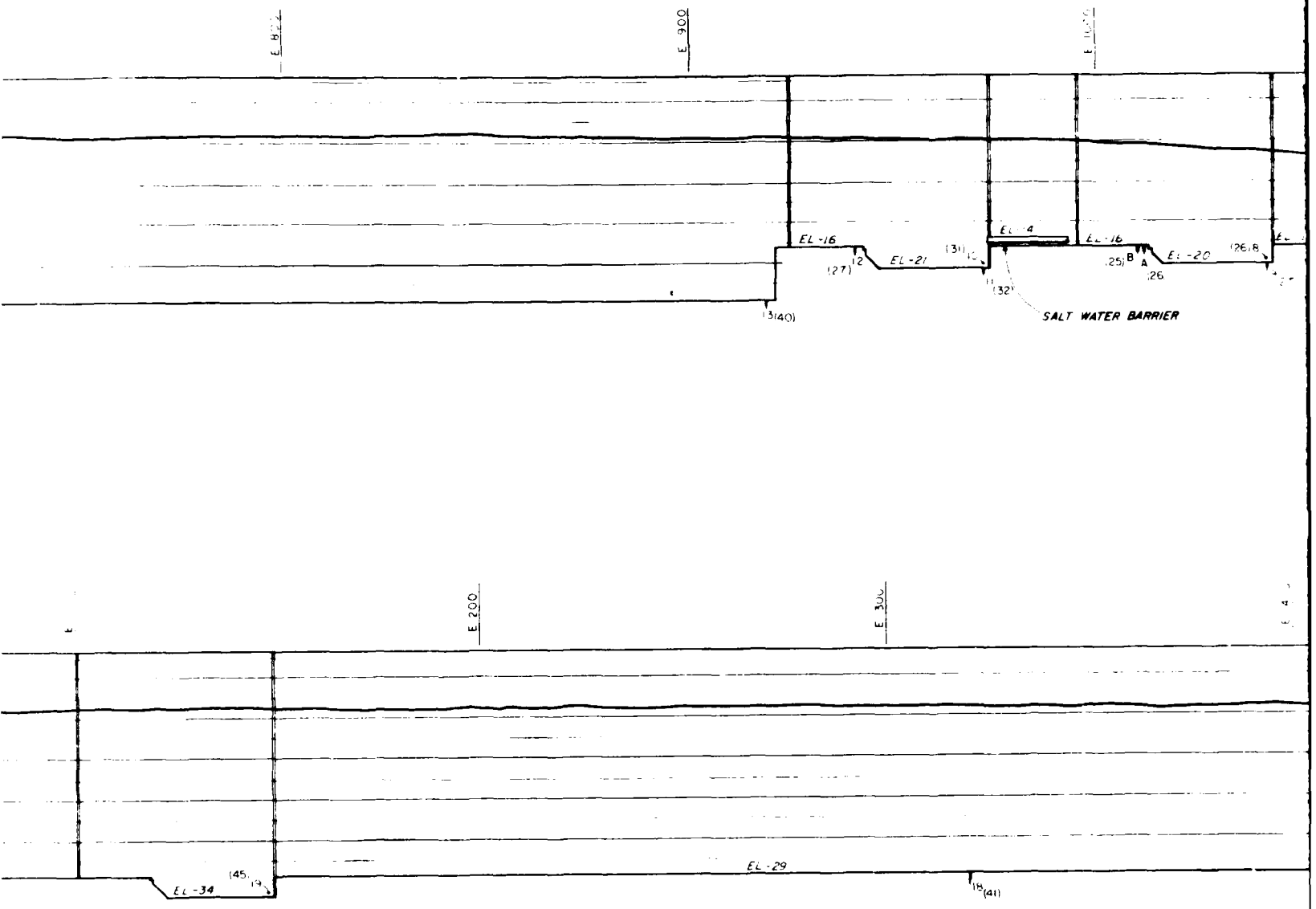
VELOCITIES

FOREBAY EL 22; TAILWATER EL+12
FREE FLOW

PLATE 15


+20
+10
0
-10
-20
MATCH LINE
EL -29
(41)

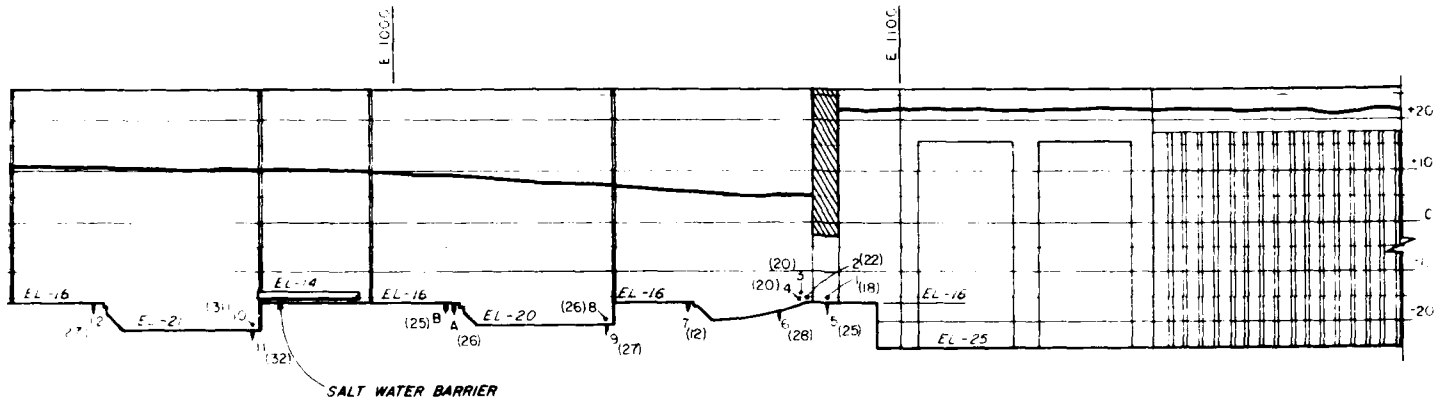

+10
0
-10
-20
EL -29
(45)
EL -34
EL -29
EL -34
(46)

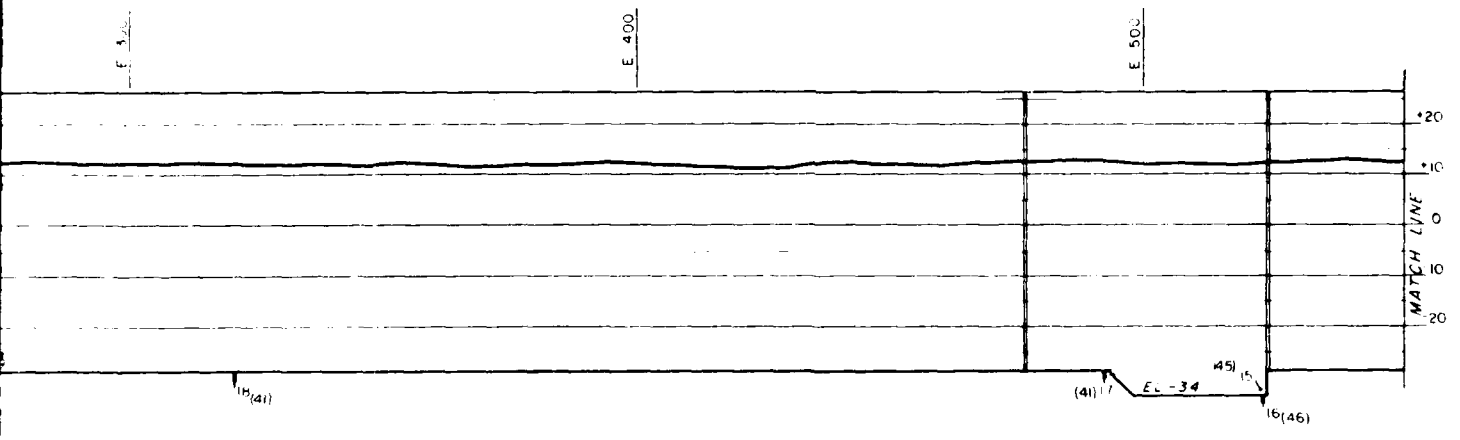


LEGEND

—— WATER-SURFACE PROFILE ALONG RIGHT WALL

(26) PRESSURE IN FEET OF WATER





LOCK DISCHARGE 21 500 CFS

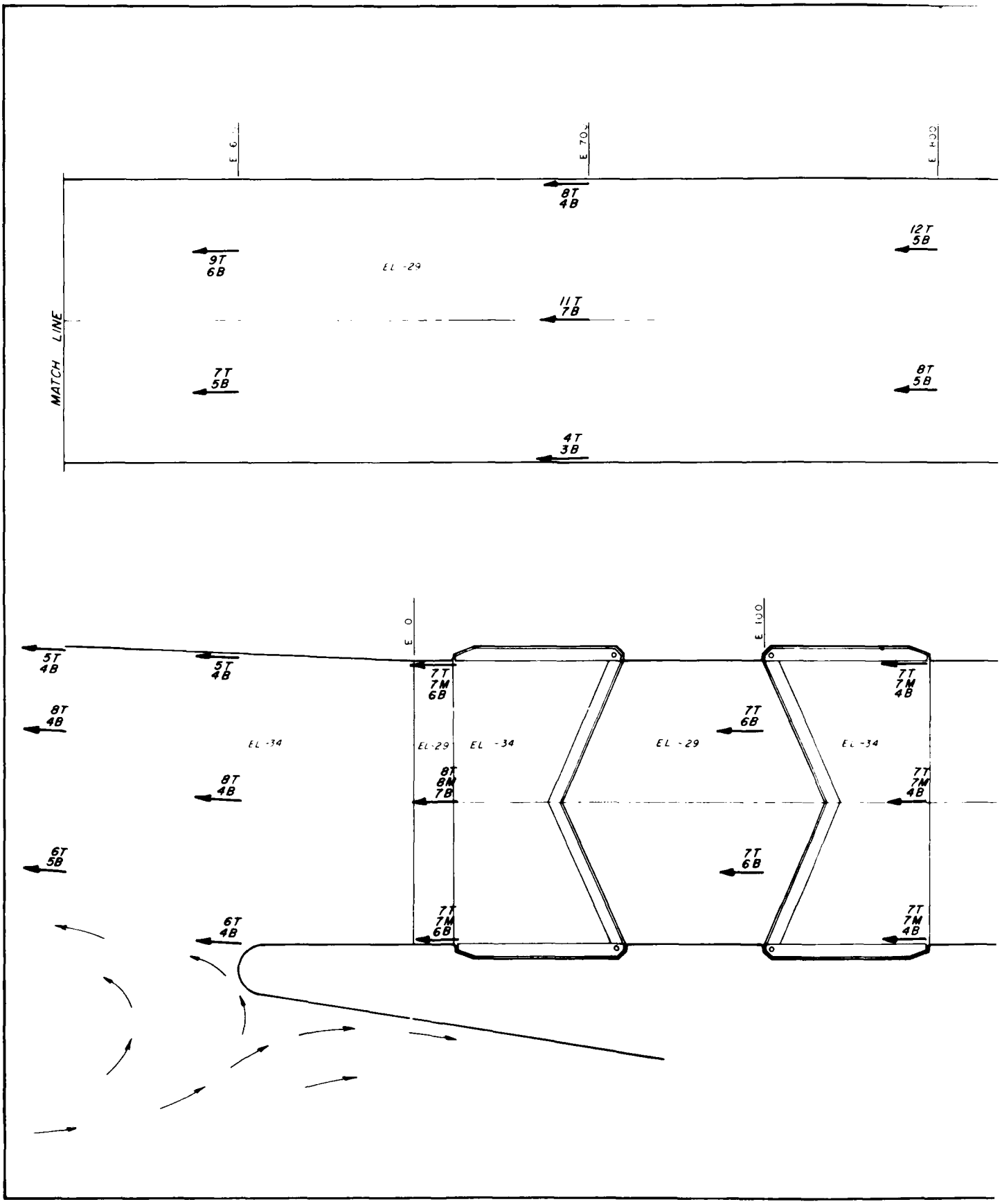
WATER SURFACE AND PRESSURES

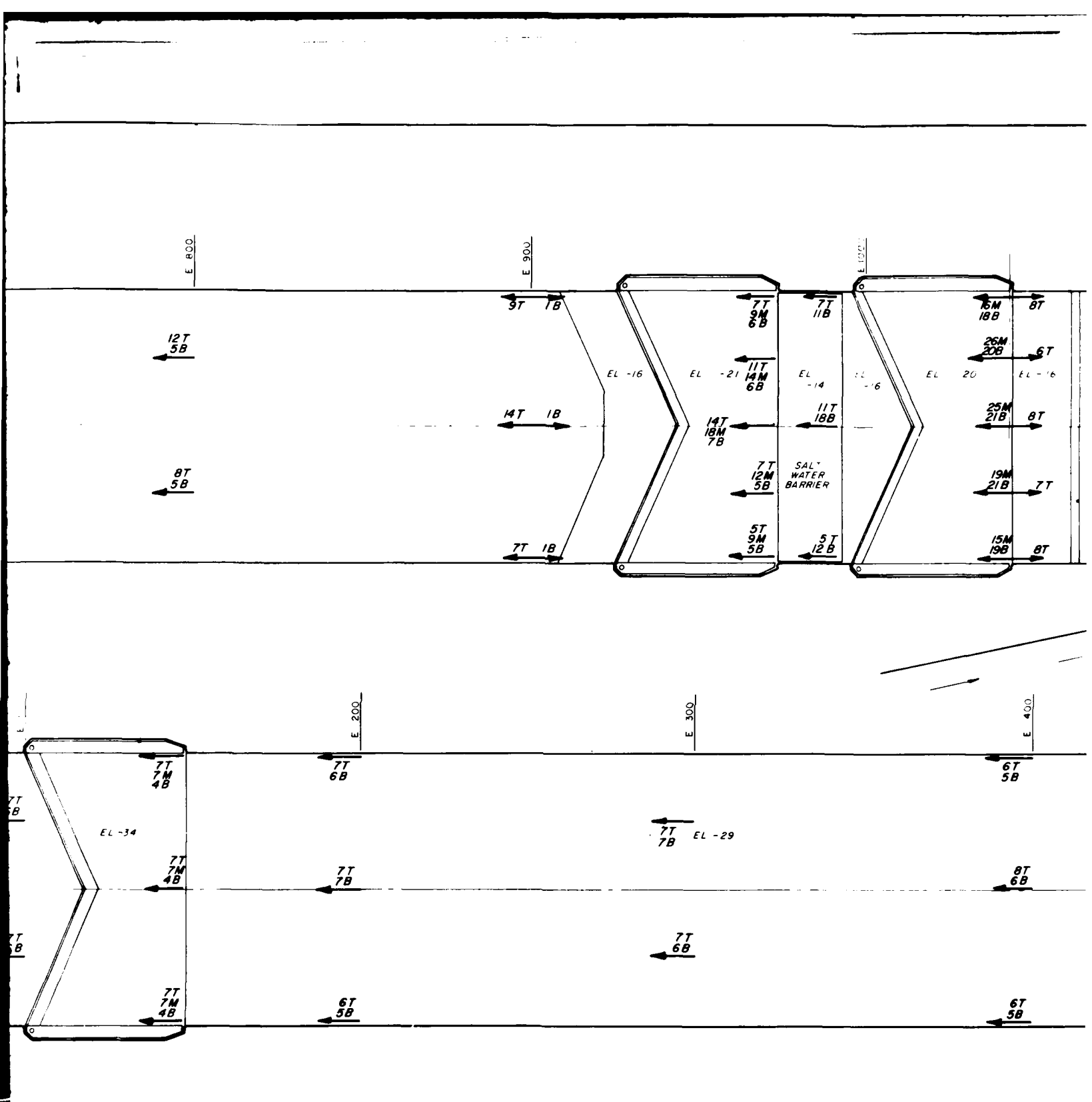
FOREBAY EL 22; TAILWATER EL +12

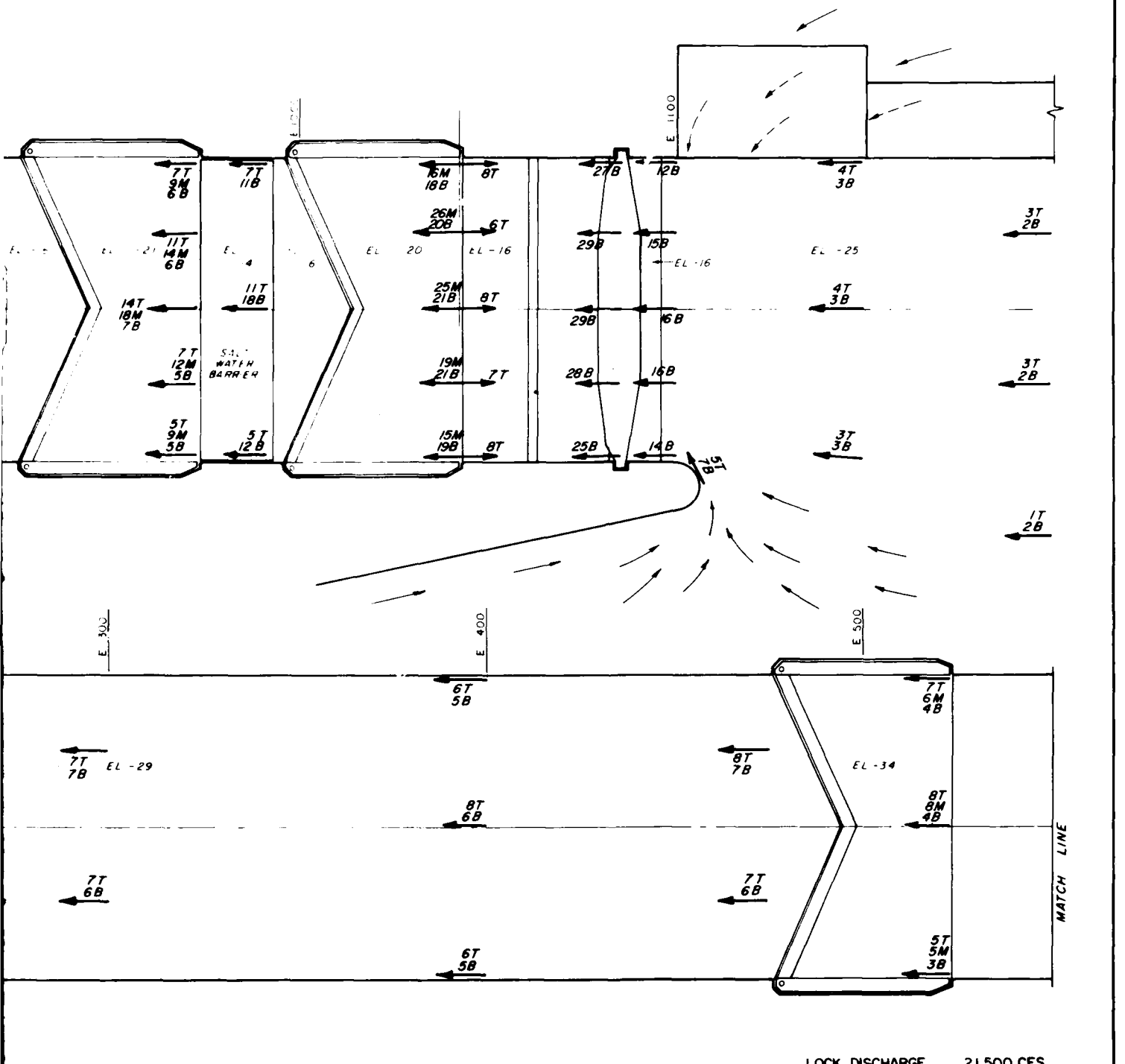
BULKHEAD OPEN 13 FT

3

PLATE 16


E 70
8T
4B
12T
5B
9T
6B
EL -29
11T
7B
MATCH LINE
7T
5B
8T
5B
4T
3B
E 0
E 100
5T
4B
5T
4B
7T
7M
6B
7T
7M
4B
8T
4B
EL -34
EL -29
EL -34
EL -29
EL -34
7T
6B
8T
4B
8T
6M
7B
7T
7M
4B
6T
5B
7T
6B
6T
4B
7T
7M
6B
7T
7M
4B


E 800
E 900
E 1000
E 200
E 300
E 400
12T 5B
8T 5B
9T 1B
14T 1B
7T 1B
EL -16
7T 9M 6B
11T 14M 6B
14T 18M 7B
7T 12M 5B
5T 9M 5B
EL -21
7T 11B
11T 18B
5T 12B
EL -14
SALT WATER BARRIER
EL -16
16M 18B
8T
26M 20B
6T
25M 21B
8T
19M 21B
7T
15M 19B
8T
EL 20
EL -16
7T 7M 4B
7T 6B
EL -34
7T 7B
EL -29
6T 5B
8T 6B
7T 6B
7T 7M 4B
6T 5B
6T 5B
LEGEND
4 VELOCITY IN FPS
T 5-FT DEPTH
M MID-DEPTH
B 5 FT ABOVE BOTTOM



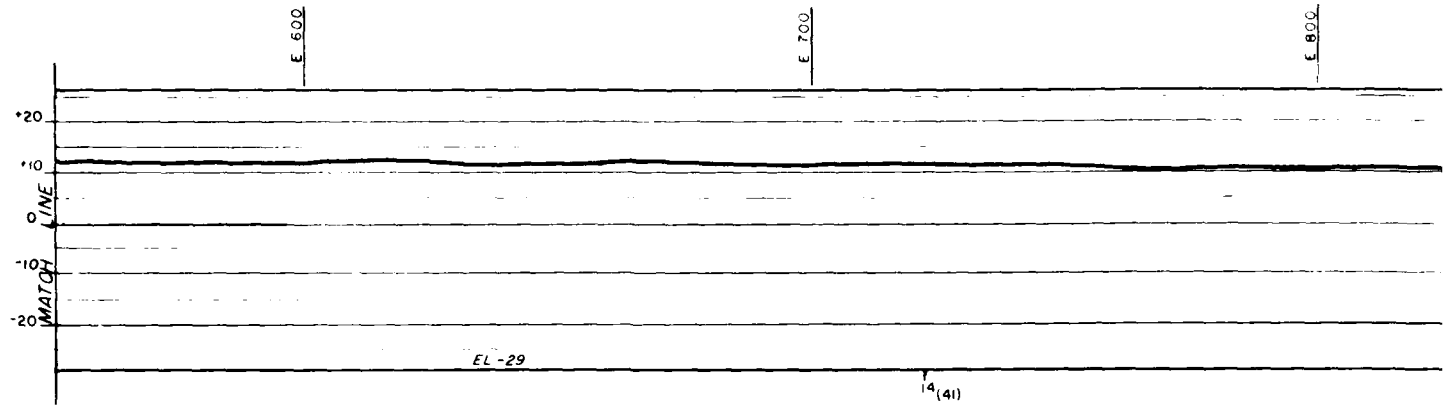
LOCK DISCHARGE 21 500 CFS

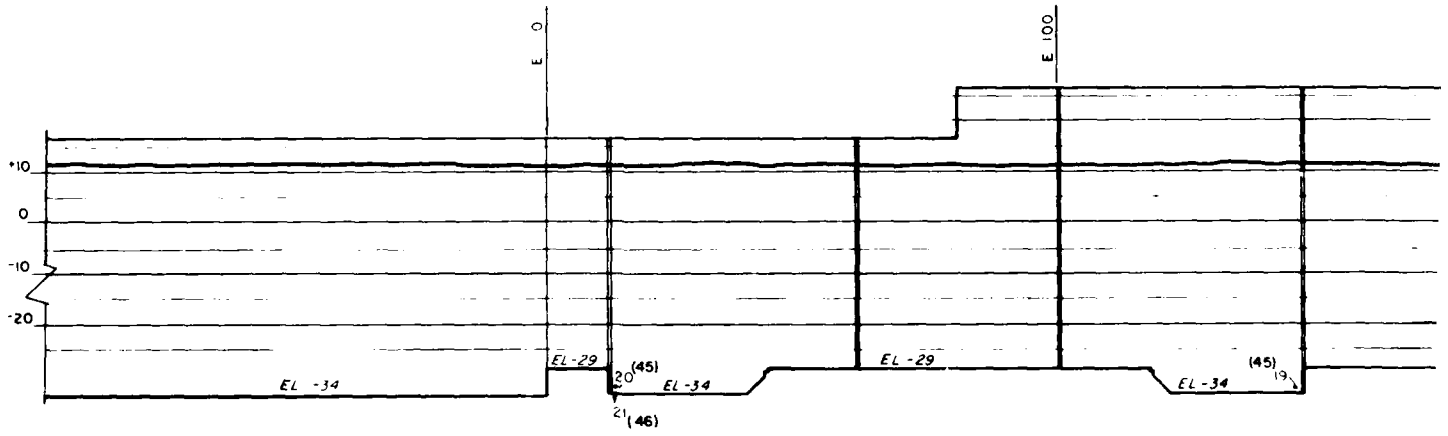
VELOCITIES

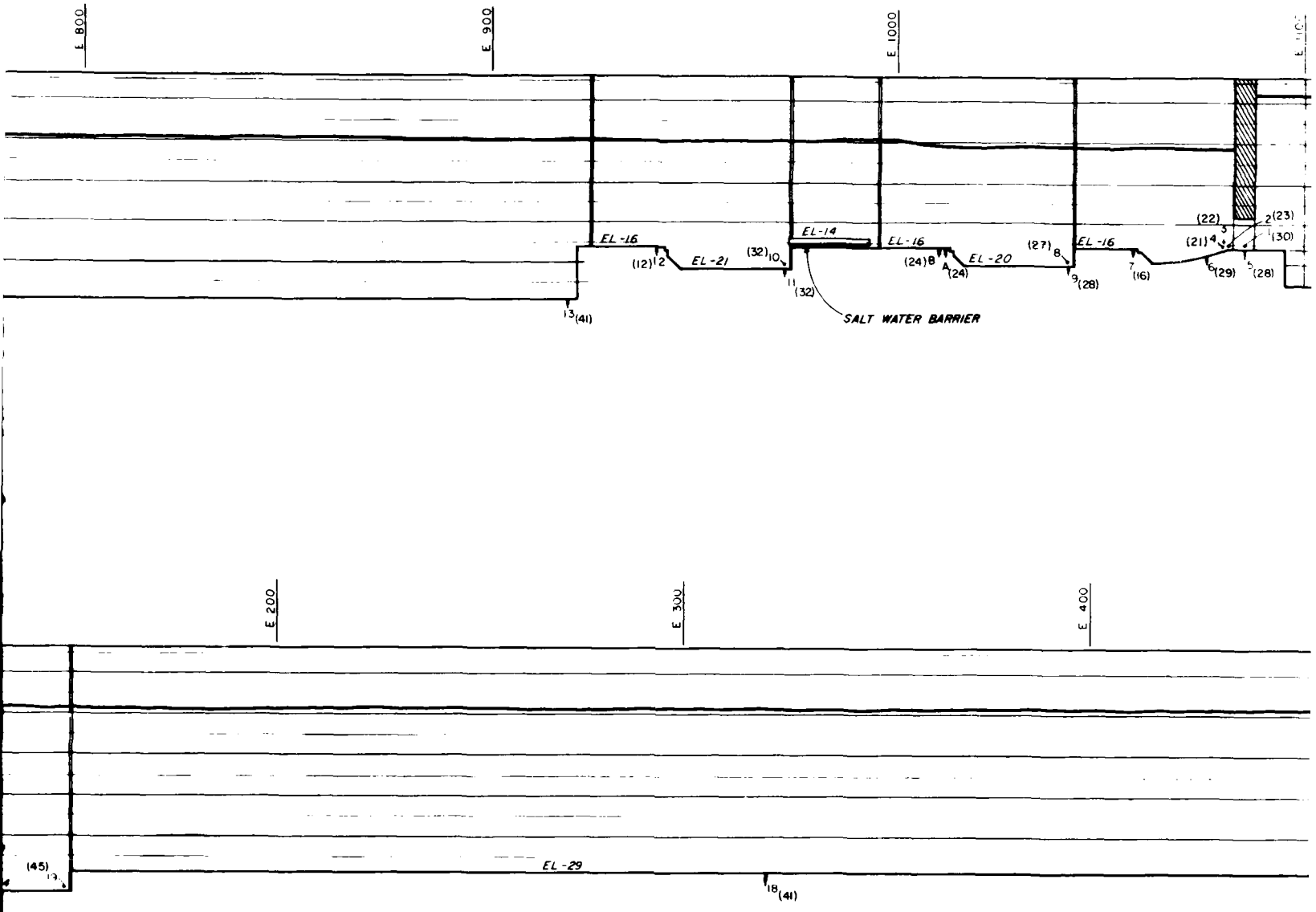
FOREBAY EL 22; TAILWATER EL+12
BULKHEAD OPEN 13FT

3

PLATE 17


E 600
E 700
E 800
+20
+10
0
-10
-20
MAT CL
EL -29
14 (41)

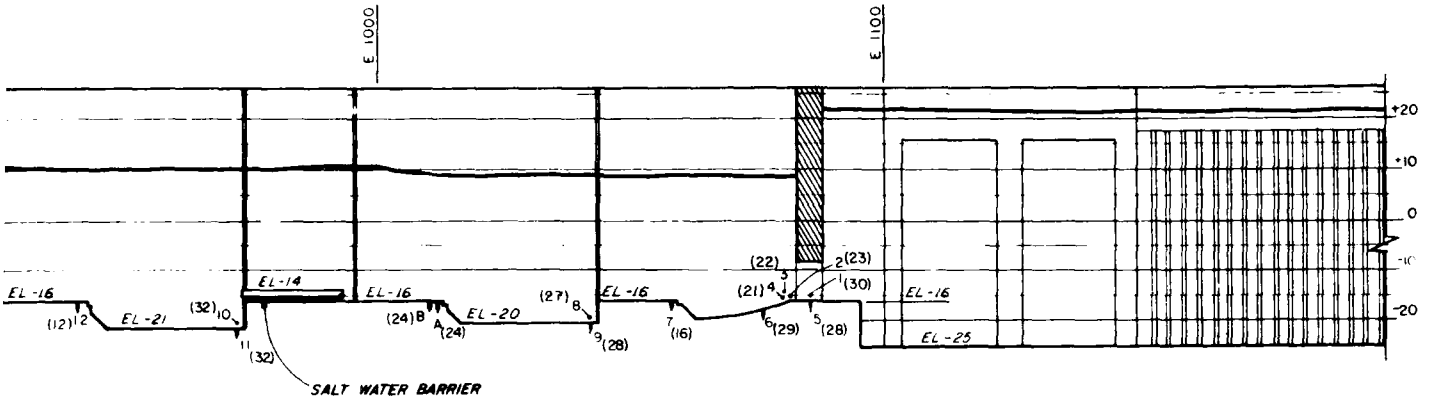

E 0
E 100
+10
0
-10
-20
EL -34
EL -29
20 (45)
EL -34
21 (46)
EL -29
EL -34
(45) 19

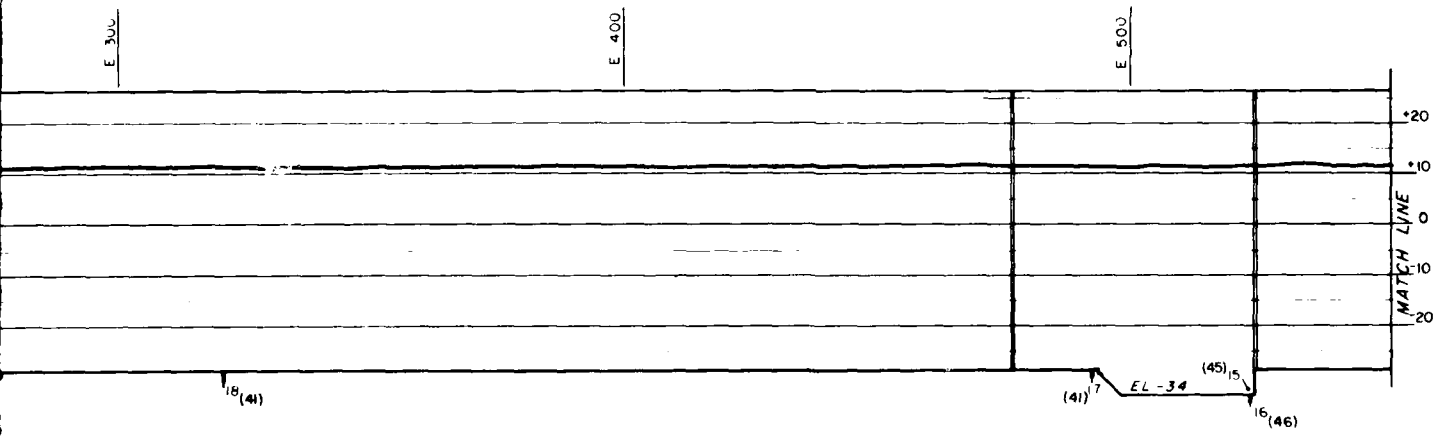


LEGEND

—— WATER-SURFACE PROFILE ALONG RIGHT WALL

(26) PRESSURE IN FEET OF WATER





LOCK DISCHARGE 12 900 CFS

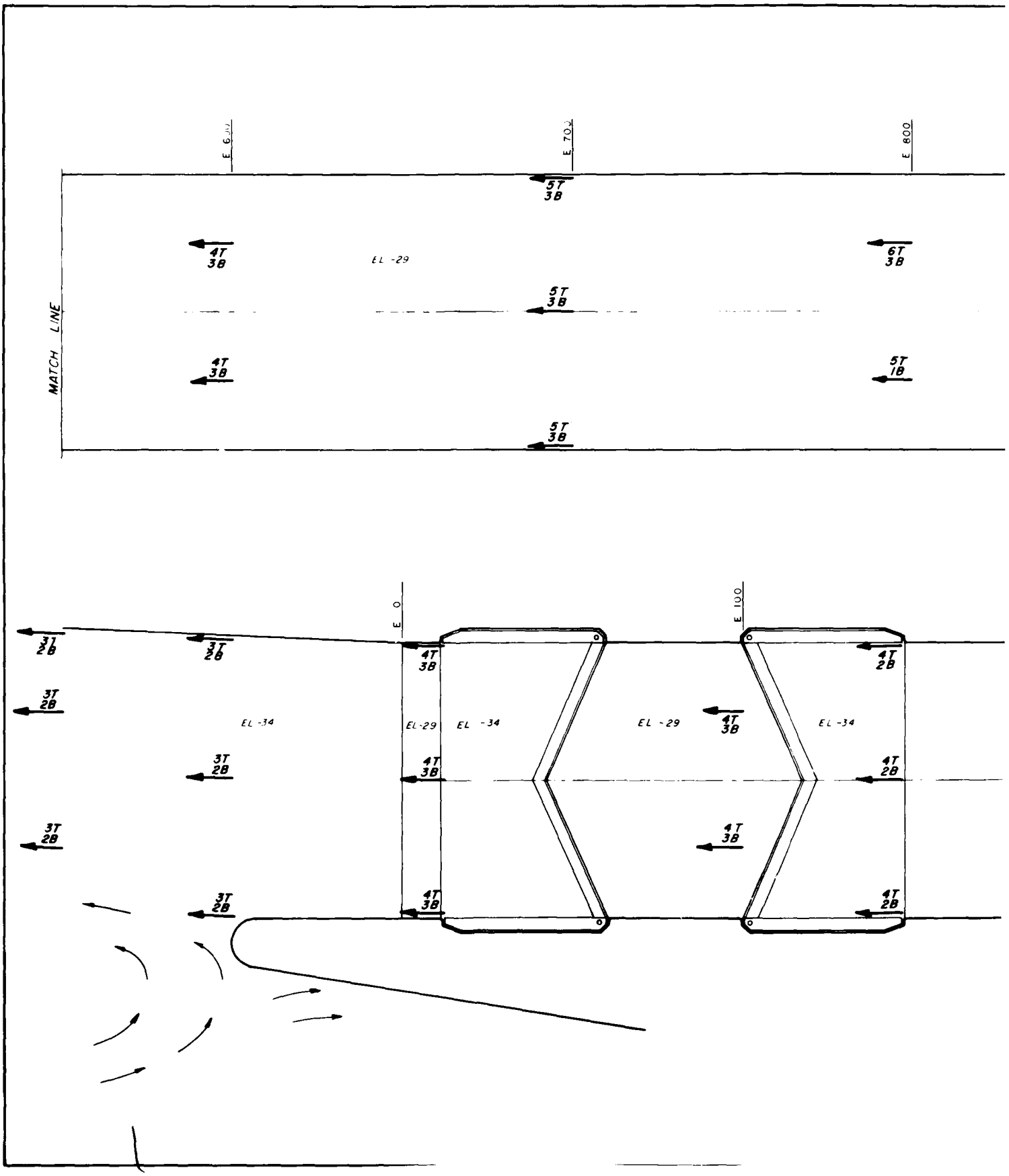
WATER SURFACE AND PRESSURES

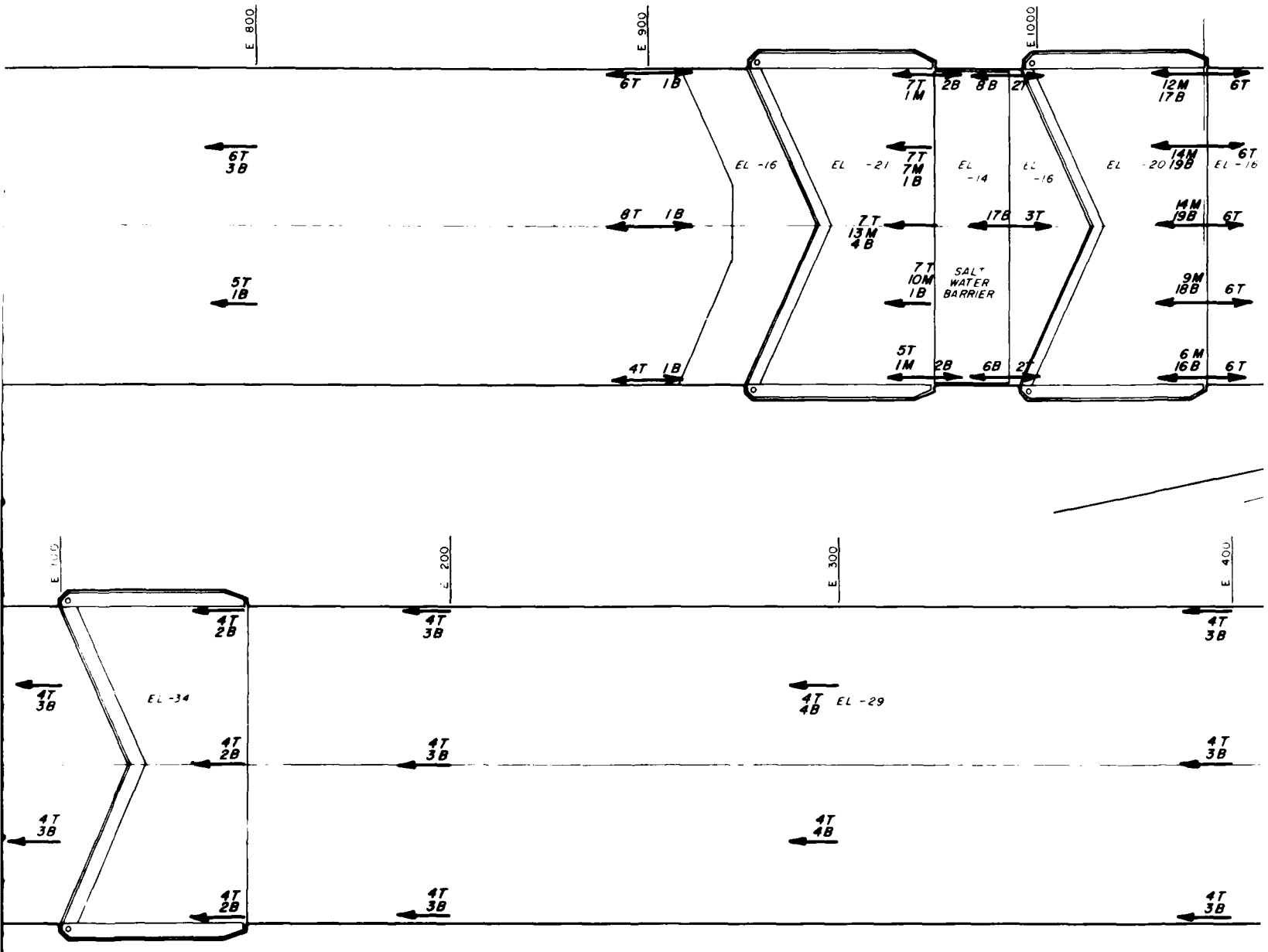
FOREBAY EL 22; TAILWATER EL +12

BULKHEAD OPEN 8 FT

3

PLATE 18


E 600
E 700
E 800
5T 3B
4T 3B
EL -29
6T 3B
5T 3B
MATCH LINE
4T 3B
5T 1B
5T 3B
E 0
E 100
3T 2B
4T 3B
4T 2B
EL -34
EL -29
EL -34
EL -29
EL -34



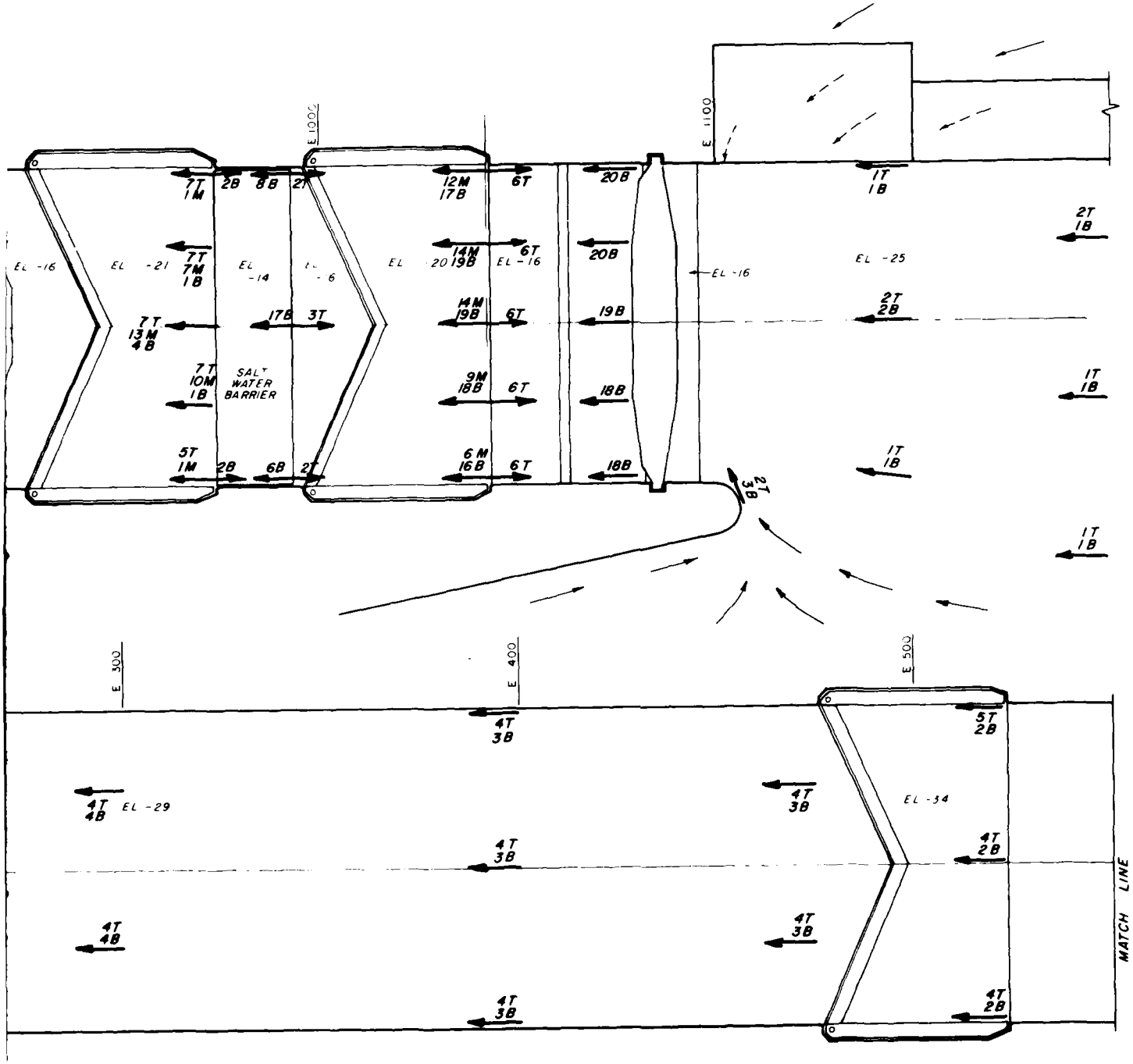
LEGEND

4 ← VELOCITY IN FPS

T 5-FT DEPTH

M MID-DEPTH

B 5 FT ABOVE BOTTOM



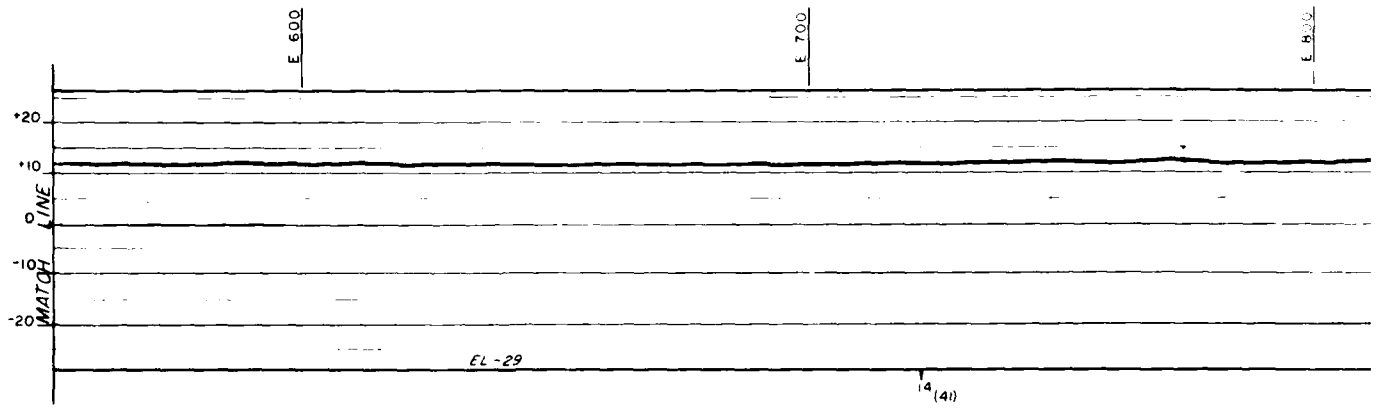
LOCK DISCHARGE 12 900 CFS

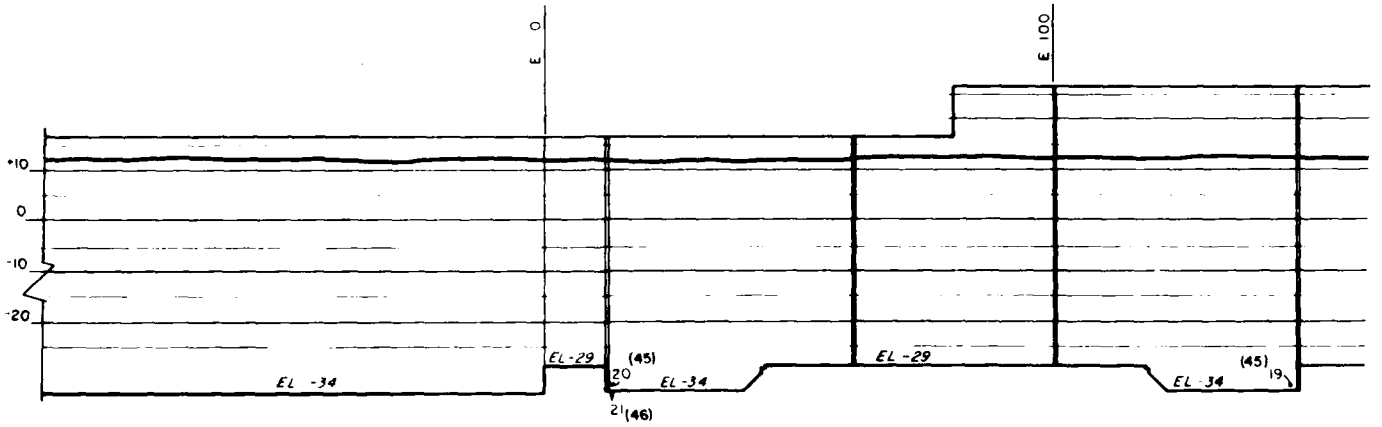
VELOCITIES

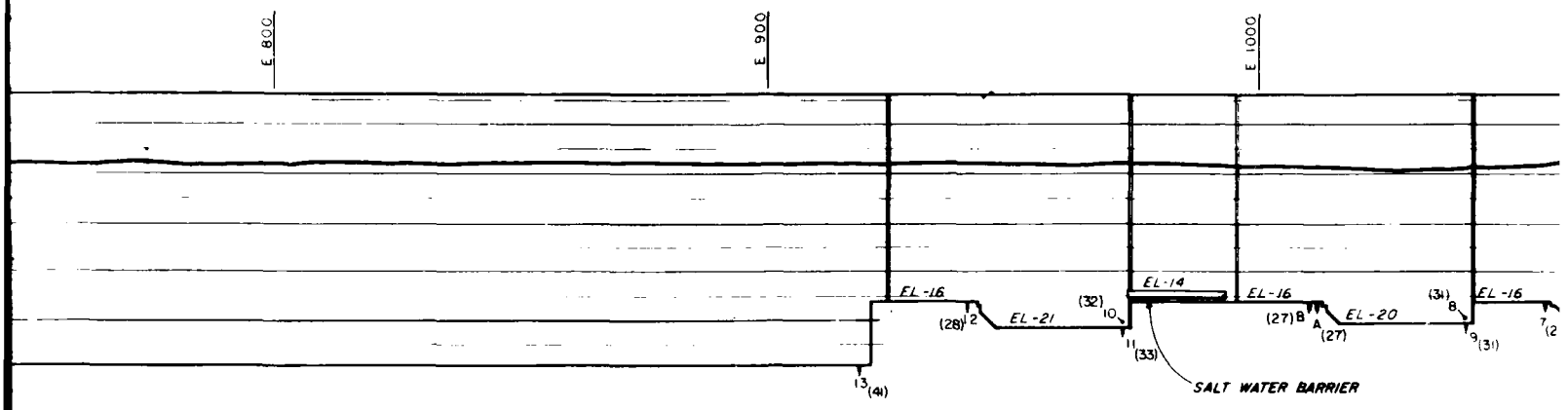
FOREBAY EL 22; TAILWATER EL +12
BULKHEAD OPEN 8 FT

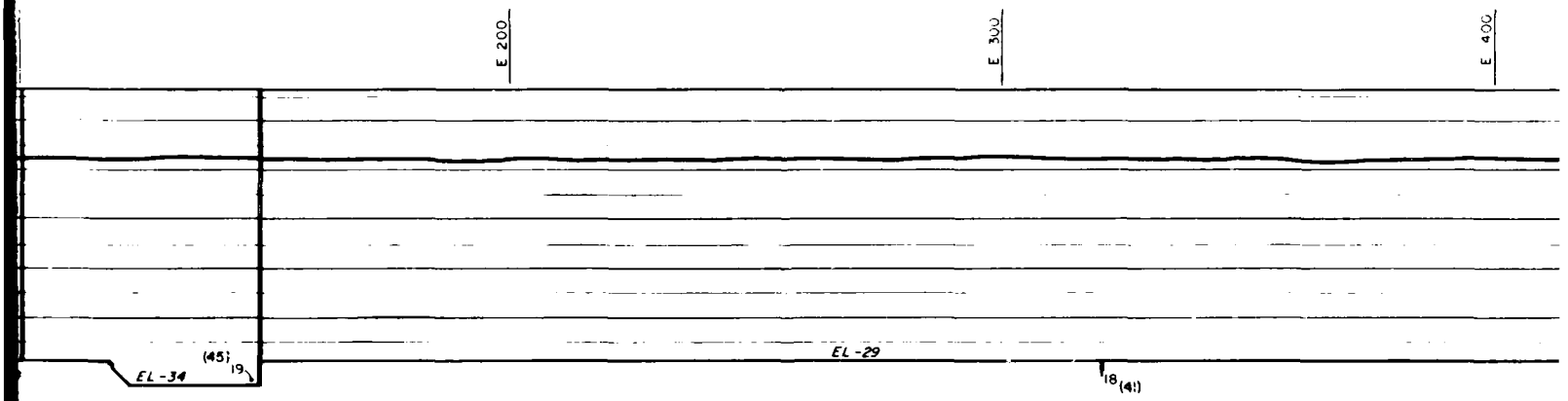
3

PLATE 19


E 600
E 700
+20
+10
0
-10
-20
MATCH LINE
EL -29
14 (41)


E 0
E 100
+10
0
-10
-20
EL -34
EL -29
(45)
20
EL -34
21 (46)
EL -29
(45)
19
EL -34

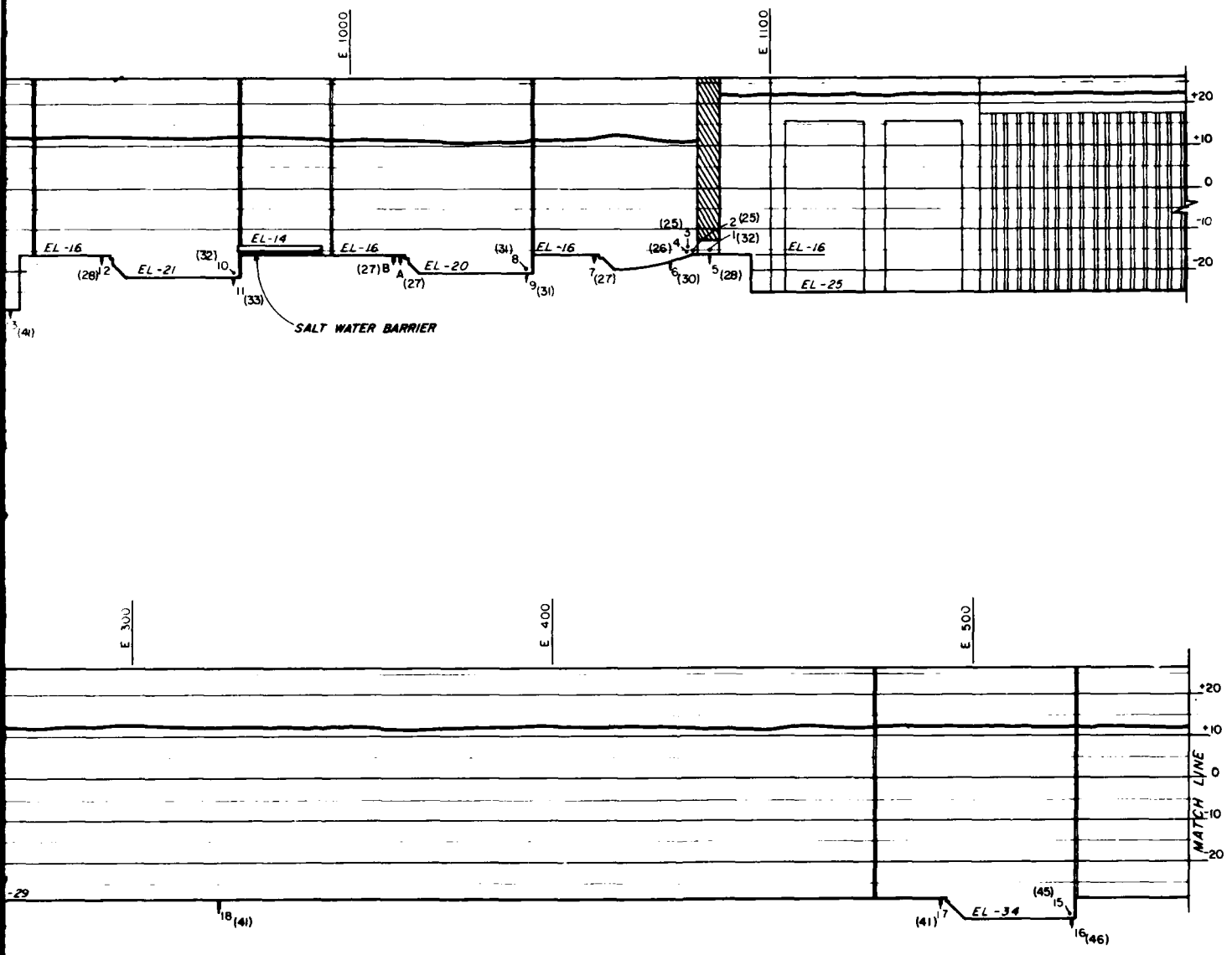




LEGEND

—— WATER-SURFACE PROFILE ALONG RIGHT WALL

(26) PRESSURE IN FEET OF WATER



LOCK DISCHARGE 4 100 CFS

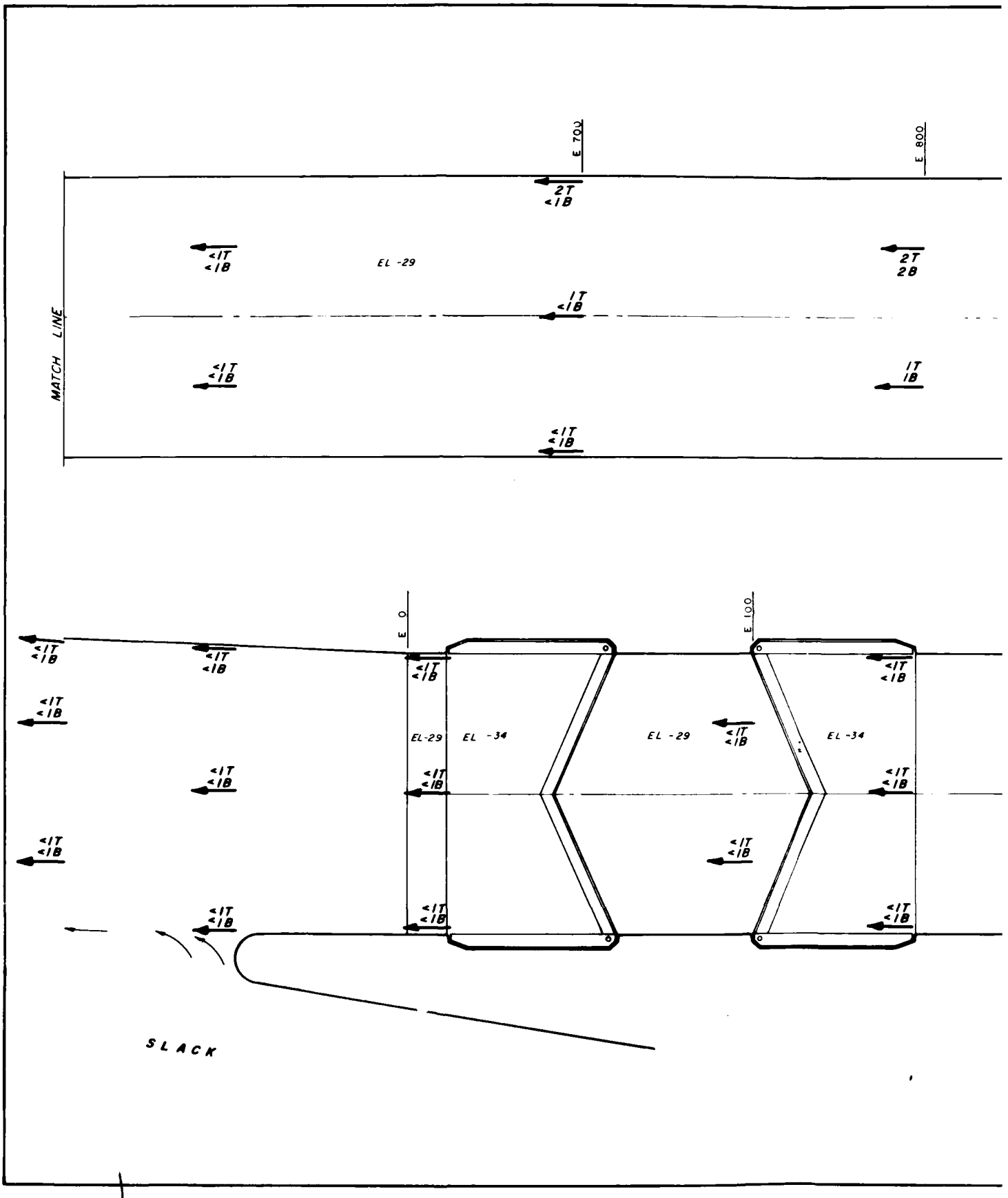
WATER SURFACE AND PRESSURES

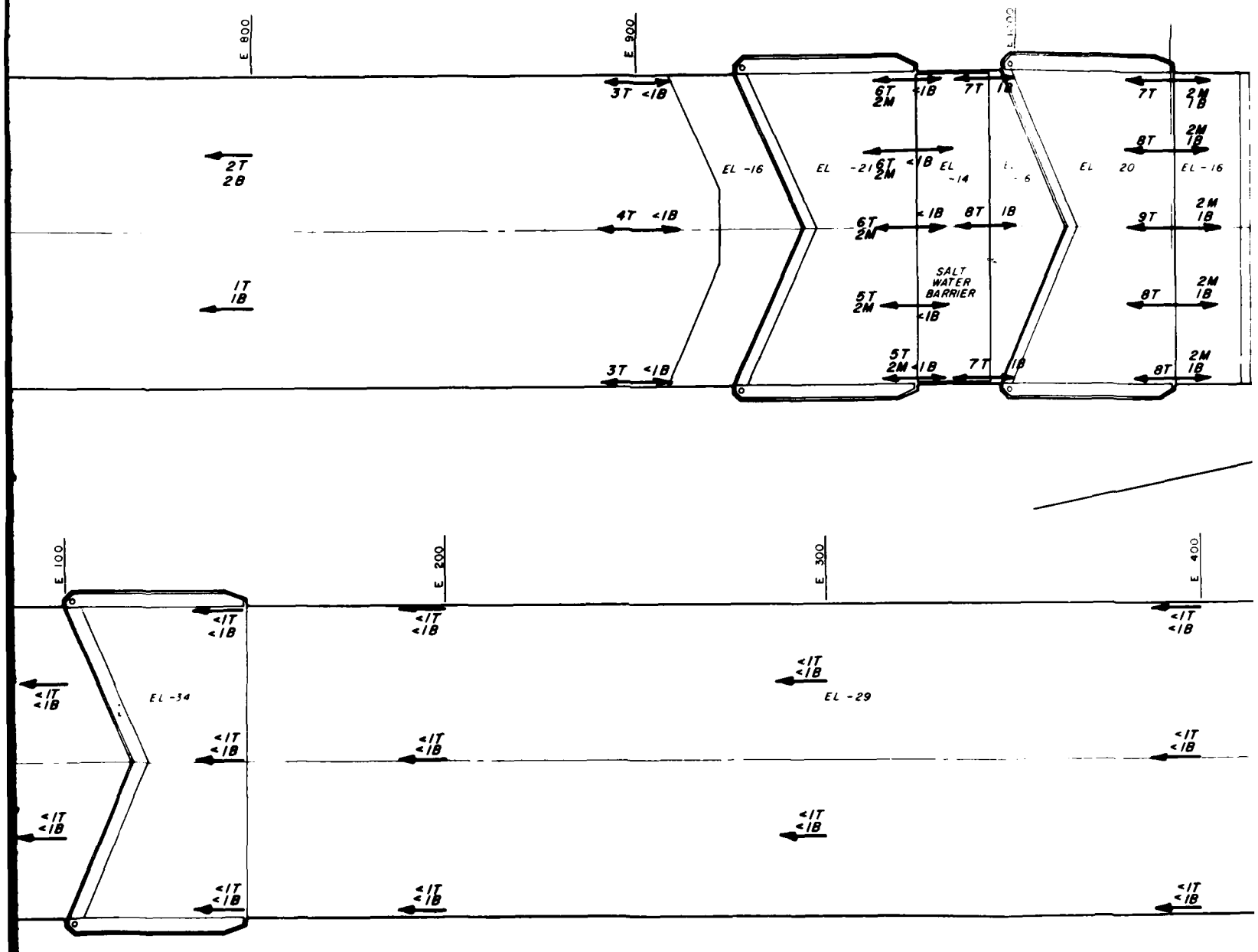
FOREBAY EL 22; TAILWATER EL+12

BULKHEAD OPEN 3 FT

3

PLATE 20


E 700
E 800
2T
<1B
<1T
<1B
EL -29
2T
2B
1T
<1B
MATCH LINE
<1T
<1B
1T
1B
<1T
<1B
E 0
E 100
<1T
<1B
EL-29
EL -34
EL -29
EL -34
SLACK



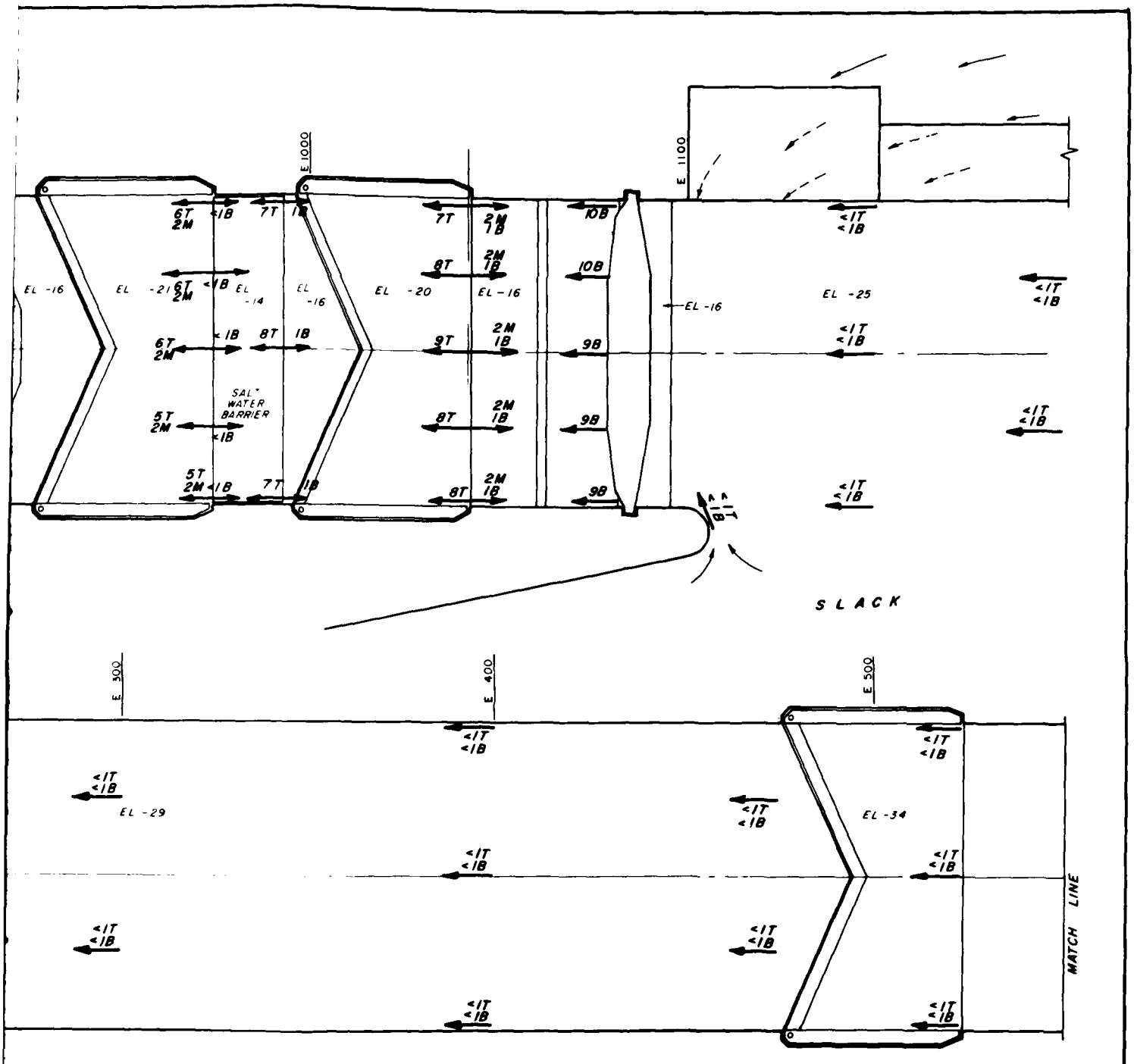
LEGEND

4 VELOCITY IN FPS

T 5-FT DEPTH

M MID-DEPTH

B 5 FT ABOVE BOTTOM



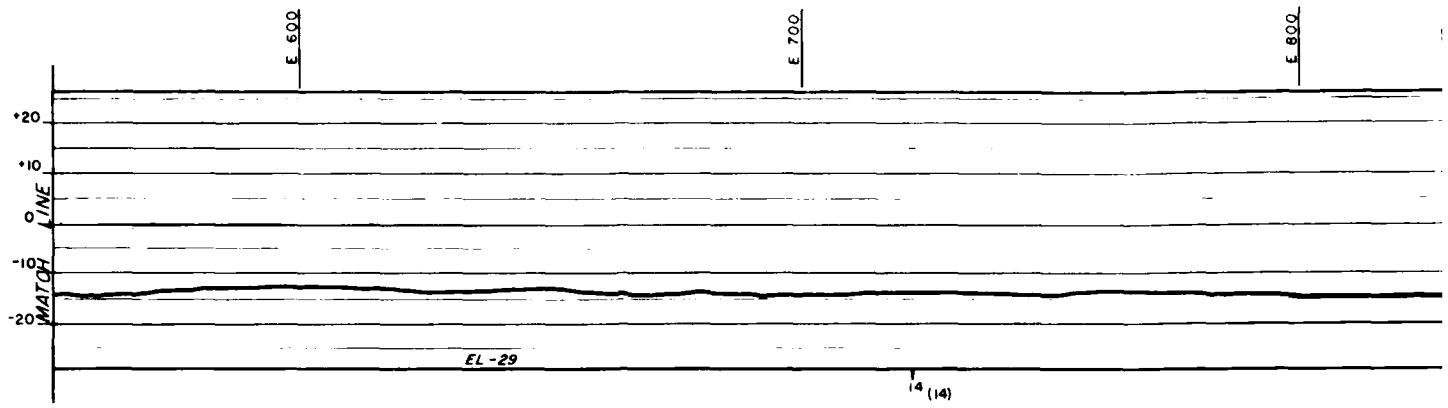
LOCK DISCHARGE 4100 CFS

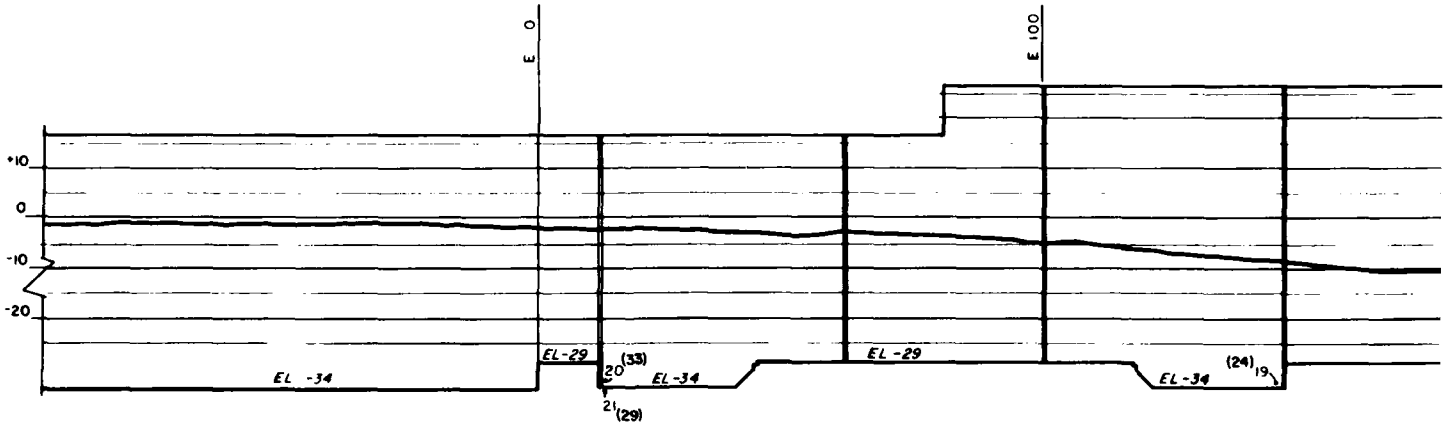
VELOCITIES

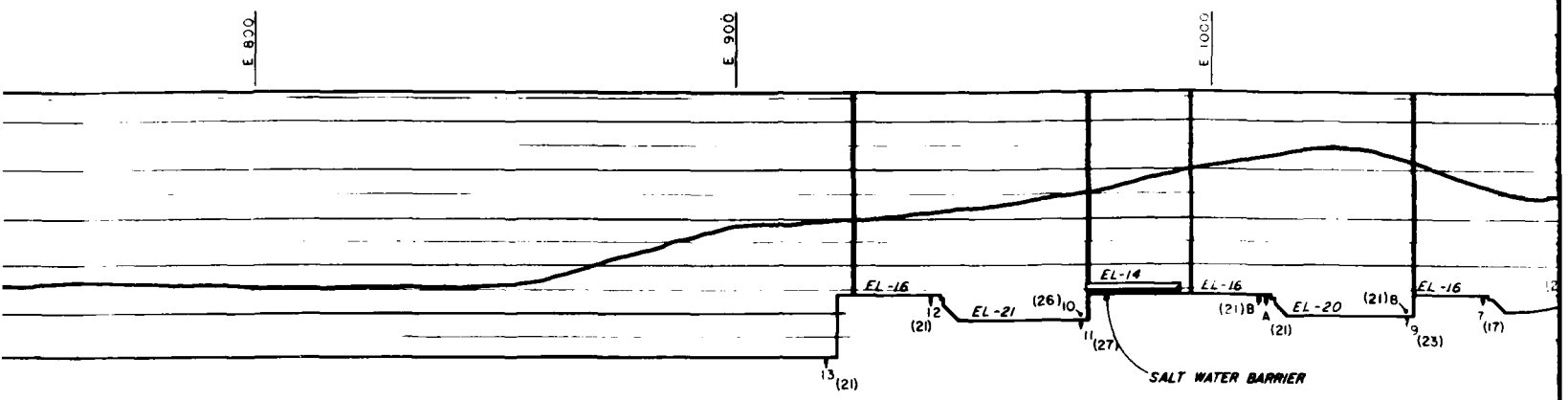
FOREBAY EL 22; TAILWATER EL +12
BULKHEAD OPEN 3FT

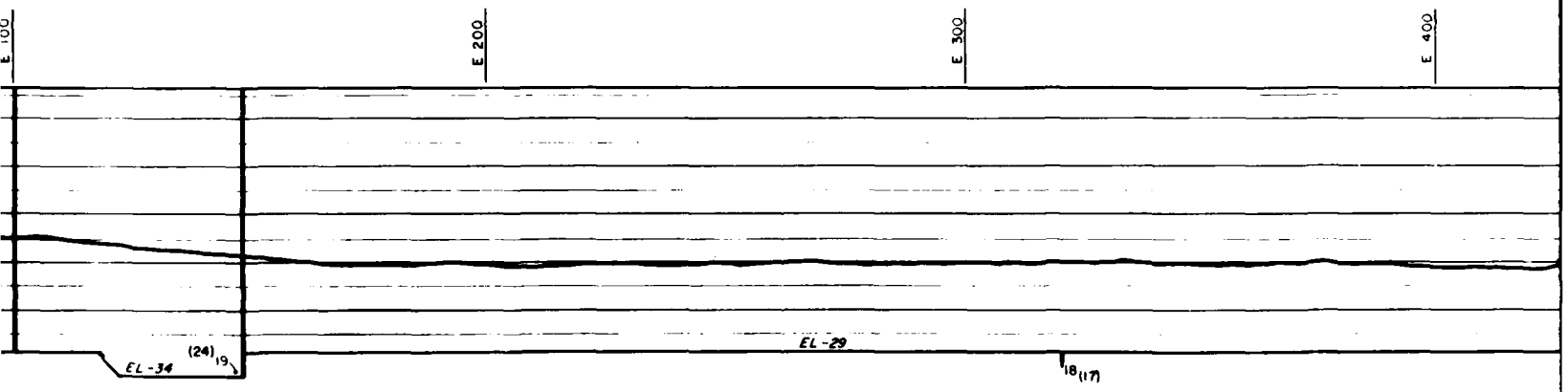
3

PLATE 21


E 600
E 700
E 800
+20
+10
0
-10
-20
MATCH LINE
EL -29
14 (14)


E 0
E 100
+10
0
-10
-20
EL -34
EL -29
20 (33)
EL -34
21 (29)
EL -29
EL -34
(24) 19

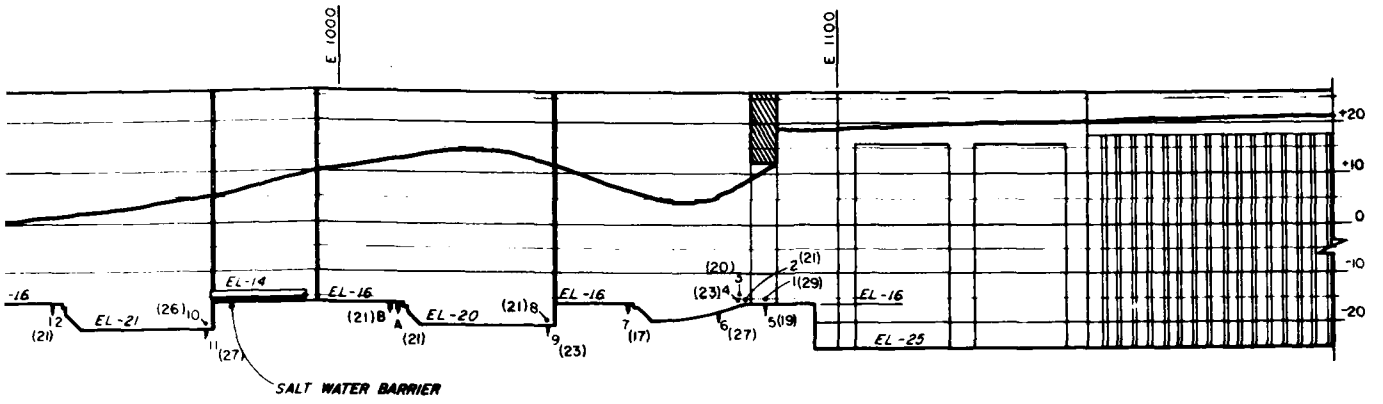


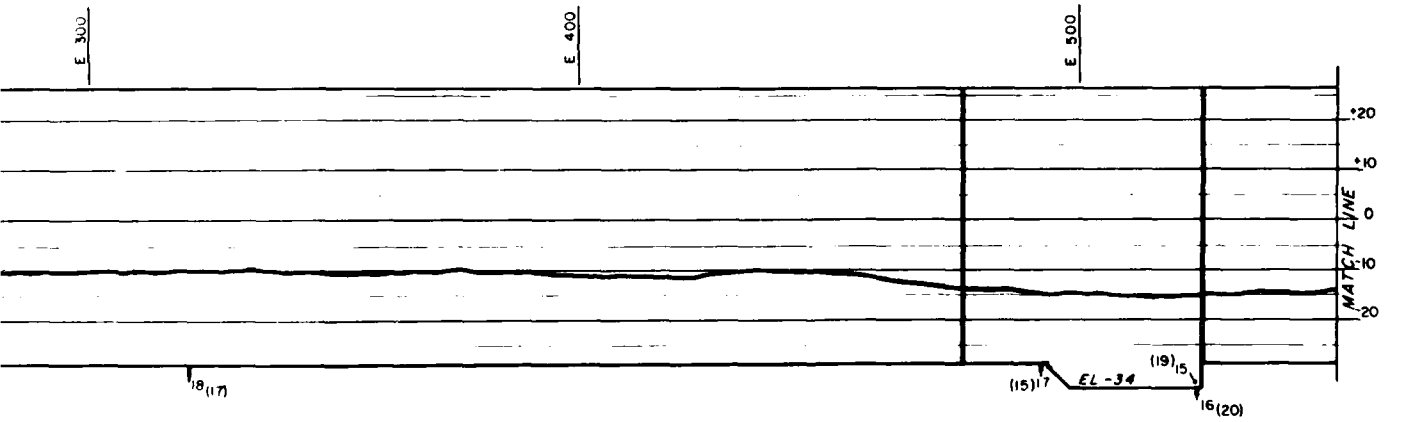


LEGEND

—— WATER-SURFACE PROFILE ALONG RIGHT WALL

(26) PRESSURE IN FEET OF WATER





LOCK DISCHARGE 45 500 CFS

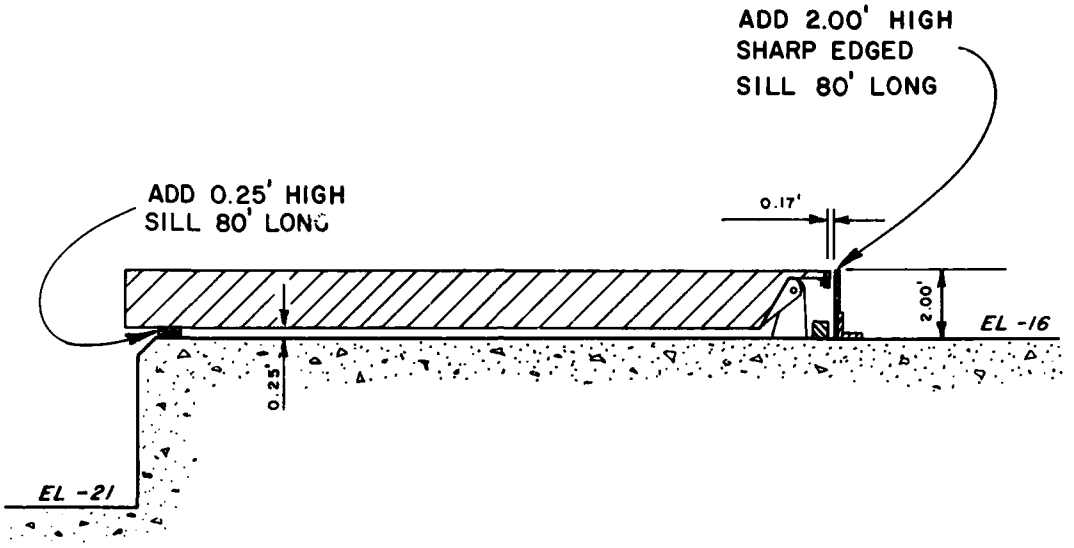
WATER SURFACE AND PRESSURES

FOREBAY EL 22; TAILWATER EL -2

BULKHEAD OPEN 28 FT

3

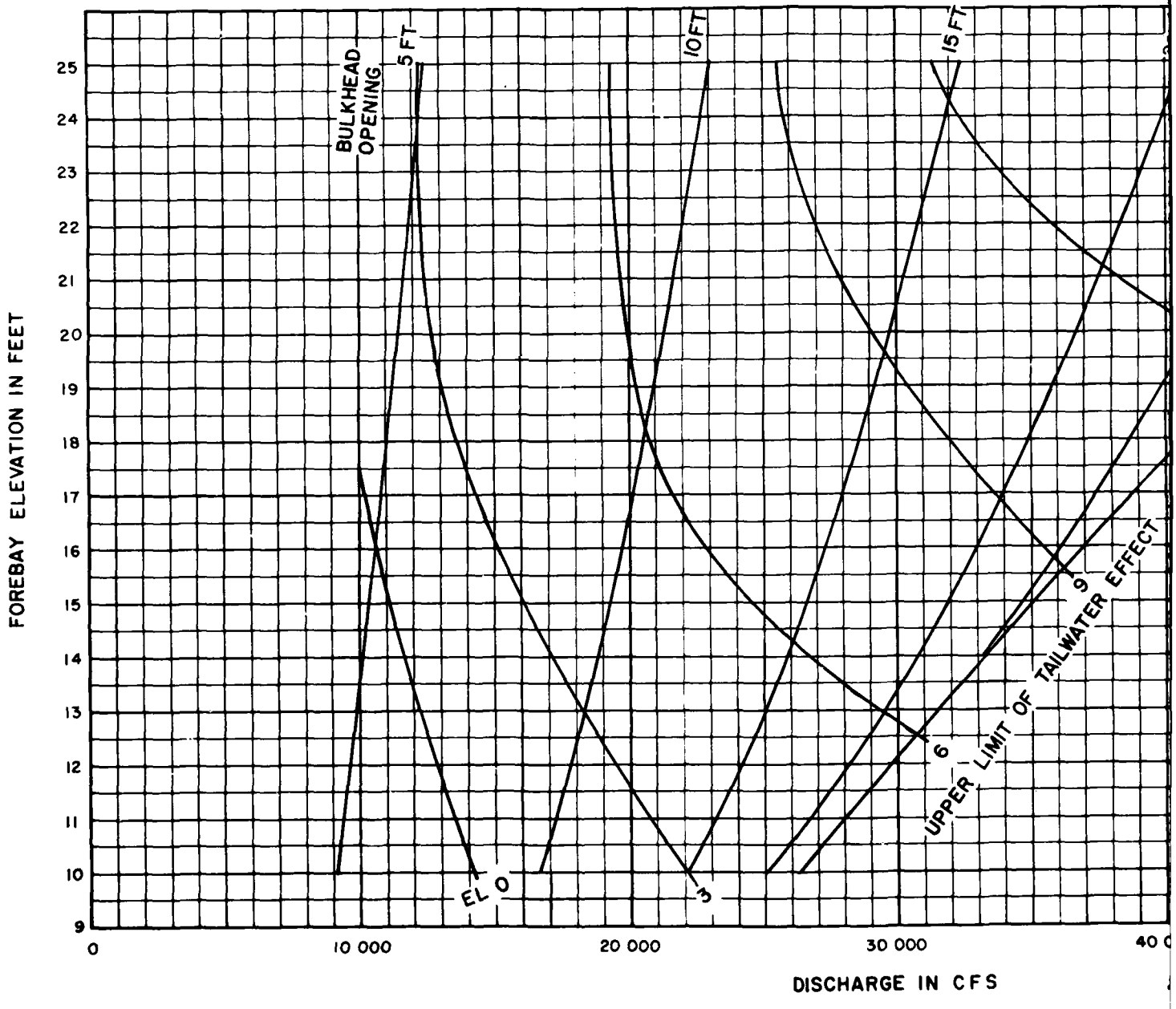
PLATE 22

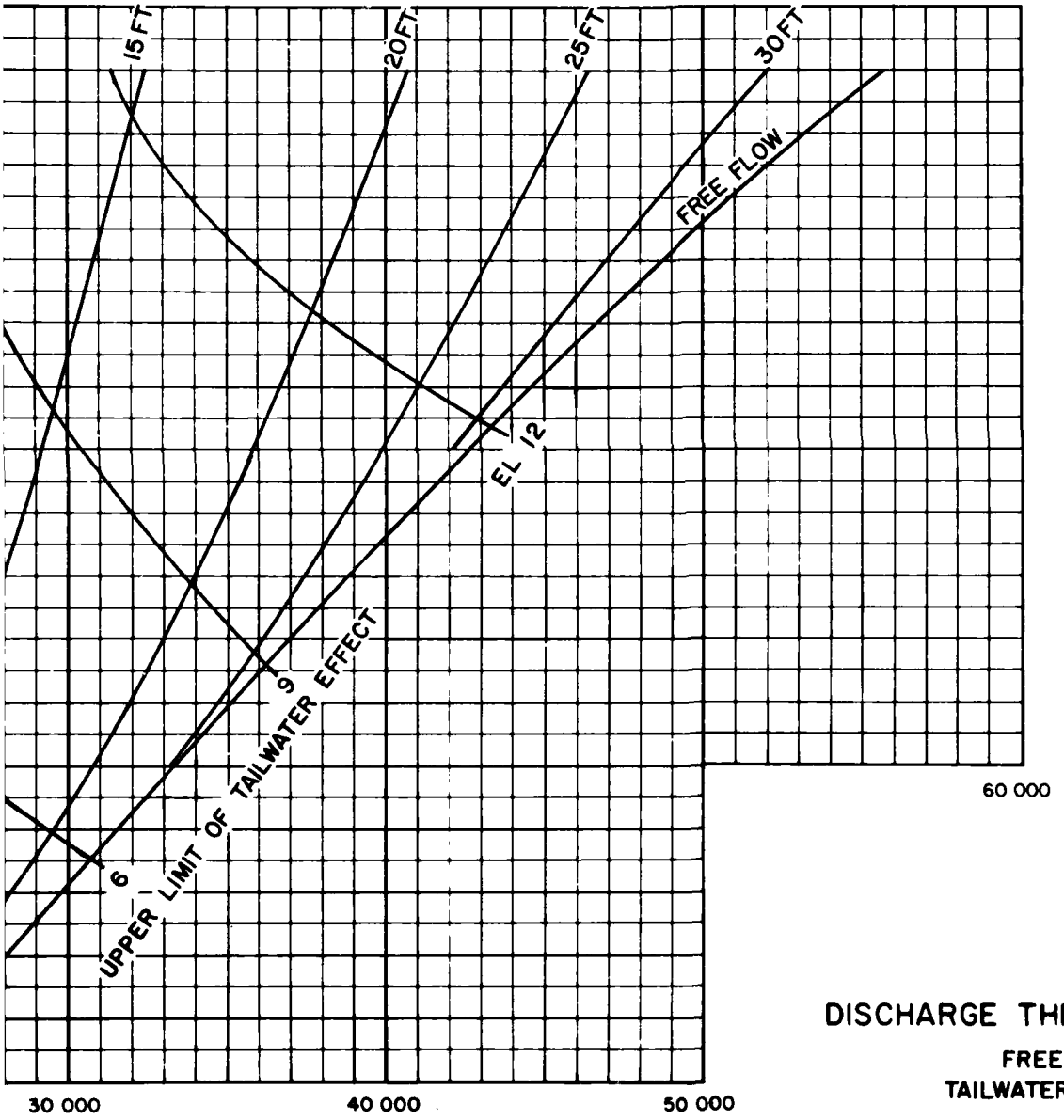


SALT WATER BARRIER

MODIFICATIONS TO
PREVENT FLUTTER

PLATE 23


FOREBAY ELEVATION IN FEET
DISCHARGE IN CFS
BULKHEAD OPENING
5 FT
10 FT
15 FT
EL 0
3
6
9
UPPER LIMIT OF TAILWATER EFFECT
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
0
10 000
20 000
30 000

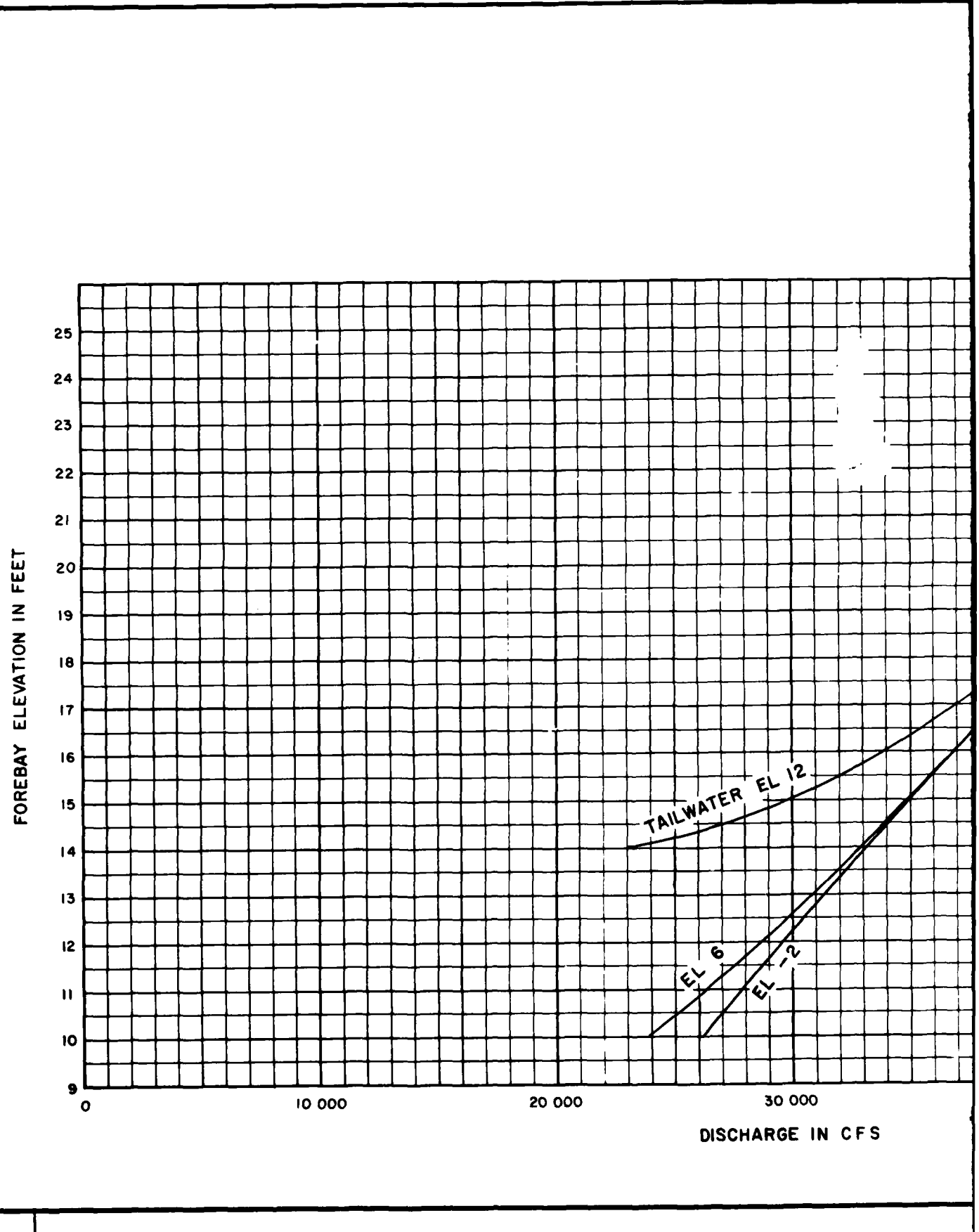


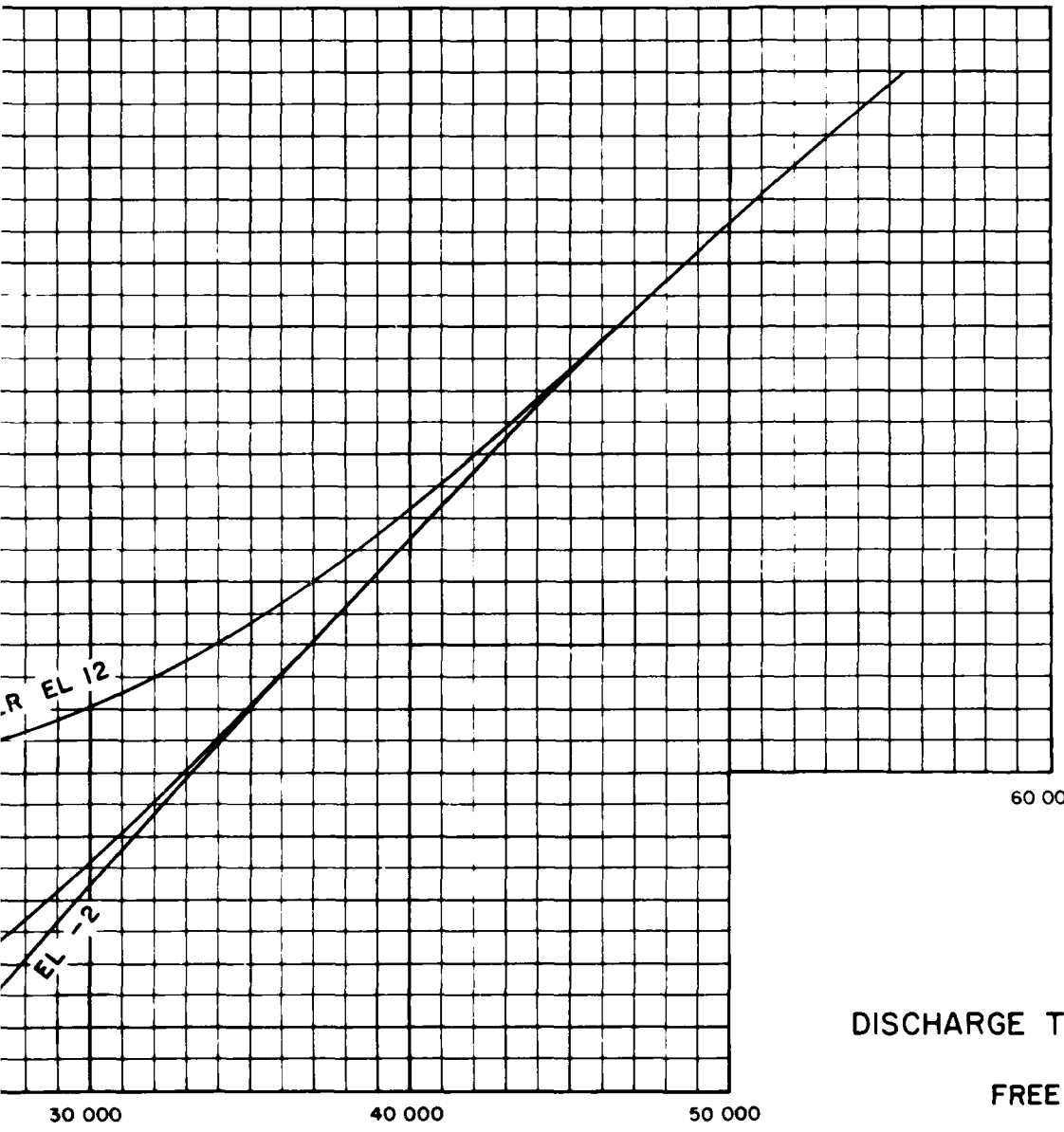
DISCHARGE THROUGH LOCK

FREE OF
TAILWATER EFFECT

IARGE IN CFS

2


FOREBAY ELEVATION IN FEET
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
0
10 000
20 000
30 000
DISCHARGE IN CFS
TAILWATER EL 12
EL 6
EL -2



DISCHARGE THROUGH LOCK

FREE FLOW

PLATE 25