prepared for

DEPARTMENT OF THE ARMY

NEW ENGLAND DIVISION, CORPS OF ENGINEERS

WALTHAM, MASSACHUSETTS 02254-9149

for

REVIEW OF STRUCTURAL STABILITY

WESTVILLE LAKE DAM

STURBRIDGE, MASSACHUSETTS

APPENDIX B

STABILITY COMPUTATIONS

submitted by

ENGINEERS
SURVEYORS
PLANNERS
GEOLOGISTS
MUNICIPAL SERVICES
LANDSCAPE ARCHITECTS
ENVIRONMENTAL CONSULTANTS

STORCH ENGINEERS

February, 1988

STORCH ENGINEERS
STORCH ASSOCIATES
Engineers - Architects - Surveyors
Landscape Architects - Environmental Specialists

JOB WESTVILLE DAM STABILITY ANALYSIS
SHEET NO. _____ OF _____
CALCULATED BY JMS DATE 10/16/87
CHECKED BY _____ DATE _____
SCALE _____

WESTVILLE DAM

STABILITY COMPUTATIONS

APPENDIX B

PRODUCT 204-1 NEBS Inc., Groton, Mass. 01471.

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INTRODUCTION:

GIVEN:

1. DESIGN MEMORANDUM NO. 6, DESIGN OF STRUCTURAL CONCRETE, MECHANICAL, ELECTRICAL, AND MISCELLANEOUS FEATURES, WESTVILL DAM, JULY 1959.

2. PERIODIC INSPECTION REPORT NO. 1, WESTVILLE LAKE, APRIL 1976.

3. RECORD DRAWINGS - WESTVILLE DAM, OCTOBER 1959.

CRITERIA USED:

1. EM 1110-1-2101 WORKING STRESSES FOR STRUCTURAL DESIGN, 1 NOV. 1963 (WITH CHANGE 2, 17 JAN 1972).

2. EM 1110-2-2200 GRAVITY DAM DESIGN, 25 SEPT. 1958 (WITH CHANGE 2, NOV. 1960).

3. EM 1110-2-2400 STRUCTURAL DESIGN OF SPILLWAYS AND OUTLET WORKS, 2 NOV. 1964.

4. EM 1110-2-2501 WALL DESIGN: FLOOD WALLS, JAN 1948 (WITH CHANGE 3, 18 JUNE 1962).

5. EM 1110-2-2502 RETAINING WALLS, 29 MAY 1961 (WITH CHANGE 3, 25 JAN. 1965).

6. ER 1110-2-1806 EARTHQUAKE DESIGN AND ANALYSIS FOR CORPS OF ENGINEERS PROJECTS, 16 MAY 1983.

PRODUCT 204-1 NEBS Inc., Groton, Mass. 01471.

INTRODUCTION: (CONT.)

CRITERIA USED: (CONT.)

7. ETL 1110-2-256 SLIDING STABILITY FOR CONCRETE STRUCTURES, 24 JUNE 1981.

8. WORKING DRAFT RETAINING AND FLOOD WALLS MANUAL, 15 JULY 1985.

REQUIRED:

REVIEW THE FOLLOWING PRINCIPLE CONCRETE STRUCTURES AND FEATURES WITH RESPECT TO THE CURRENT STABILITY CRITERIA LISTED ABOVE:

1. SPILLWAY WEIR
2. NORTH & SOUTH ABUTMENTS OF SPILLWAY
3. SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY)
4. CONTROL HOUSE MONOLITH
5. RIGHT (SOUTH) TRAINING WALL

BACKGROUND MATERIAL:

1. SPILLWAY LOADING CONDITIONS

REFERENCES: EM 1110-2-2200 PG. 7
EM 1110-2-2400 PG. 8

CASE I CONSTRUCTION CONDITION
II NORMAL OPERATING CONDITION
III INDUCED SURCHARGE CONDITION ← NOT APPLICABLE
IV FLOOD DISCHARGE CONDITION
V CONSTRUCTION CONDITION WITH EARTHQUAKE
VI NORMAL OPERATING CONDITION WITH EARTHQUAKE

REQUIREMENTS FOR STABILITY OF GRAVITY DAM FOR ALL CONDITIONS OF LOADING

1. SAFE AGAINST OVERTURNING AT ANY HORIZONTAL PLANE WITHIN THE DAM, AT THE BASE OR AT A PLANE BELOW THE BASE.
2. SAFE AGAINST SLIDING ON ANY HORIZONTAL PLANE WITHIN THE DAM, ON THE FOUNDATION, OR ON ANY HORIZONTAL OR NEARLY HORIZONTAL SEAM IN THE FOUNDATION
3. ALLOWABLE UNIT STRESSES IN THE CONCRETE OR IN THE FOUNDATION MATERIAL SHALL NOT BE EXCEEDED.

BACKGROUND MATERIAL (CONT.)

2. LOADING CONDITION NORTH AND SOUTH ABUTMENTS OF SPILLWAY

REF.: RETAINING AND FLOOD WALLS WORKING DRAFT

CASE I, USUAL LOADING: BACKFILL IN PLACE TO FINAL ELEVATION. LATERAL AND UPLIFT PRESSURES DUE TO WATER. WATER ELEVATION TO 572.0

CASE II, EXTREME LOADING: THE SAME AS LOAD CASE I, EXCEPT THAT THE WATER ELEVATION IS AT FLOOD DISCHARGE LEVEL (ELEVATION 582.5)

CASE III, EARTHQUAKE LOADING: LOAD CASE I WITH THE ADDITION OF LATERAL EARTHQUAKE FORCES. LOADING "A" INCORPORATES EARTHQUAKE FORCES IN AN UPSTREAM DIRECTION. LOADING "B" INCORPORATES EARTHQUAKE FORCES IN A DOWNSTREAM DIRECTION

BACKGROUND MATERIAL (CONT.)

3. LOADING CONDITION SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY)

REF.: RETAINING AND FLOOD WALLS WORKING DRAFT

CASE I, USUAL LOADING: BACKFILL IN PLACE TO FINAL ELEVATION. PERMANENT POOL ELEVATION IS BELOW BOTTOM OF THE WALL, AND DOES NOT EFFECT FORCES ON THE WALL.

CASE II, EXTREME LOADING: THE SAME AS CASE I EXCEPT THAT THE WATER ELEVATION IS AT FLOOD DISCHARGE LEVEL (EL. 582.5)
(REF: WESTVILLE DAM & RESERVIOR DESIGN MEMORANDUM NO. 6, PG. 13)

CASE III, EARTHQUAKE LOADING: LOAD CASE I WITH THE ADDITION OF LATERAL EARTHQUAKE FORCES.

BACKGROUND MATERIAL (CONT.)

4. LOADING CONDITION CONTROL HOUSE MONOLITH

CASE I, CONSTRUCTION CONDITION: WIND LOAD TO PRODUCE THE MOST SEVERE FOUNDATION PRESSURE

CASE II, NORMAL LOADING CONDITION: RESERVOIR AT ELEVATION 572.0, EARTH LOADS, 100 PERCENT UPLIFT.

CASE III, FLOOD CONDITION: RESERVOIR AT ELEVATION 582.5, EARTH LOADS, 100 PERCENT UPLIFT.

CASE IV, CONSTRUCTION CONDITION WITH EARTHQUAKE: SAME AS CASE I EXCEPT THAT EARTHQUAKE IS SUBSTITUTED FOR WIND.

CASE V, NORMAL LOADING CONDITION WITH EARTHQUAKE: SAME AS CASE II EXCEPT THAT EARTHQUAKE FORCES ARE INCLUDED. LOADING "A" INCORPORATES EARTHQUAKE FORCES IN THE EAST-WEST DIRECTION. LOADING "B" INCORPORATES EARTHQUAKE FORCES IN THE NORTH-SOUTH DIRECTION.

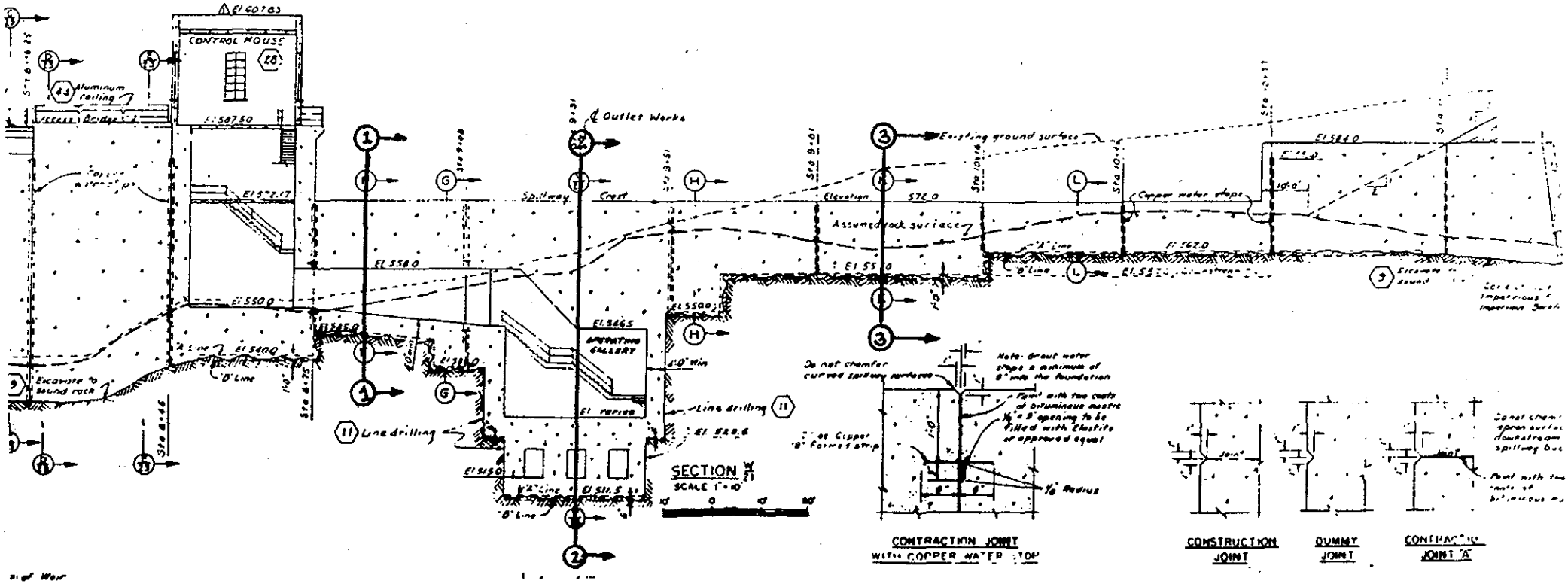
BACKGROUND MATERIAL (CONT.)

5. LOADING CONDITION RIGHT (SOUTH) TRAINING WALL
REF.: RETAINING AND FLOOD WALLS - WORKING DRAFT

CASE I, USUAL LOADING: BACKFILL TO PLACE AT FINAL ELEVATION. NO HYDROSTATIC PRESSURE ON THE WALL.

CASE II, EXTREME LOADING: THE SAME AS LOADING CONDITION I EXCEPT FOR THE ADDITION OF SHORT DURATION HYDROSTATIC FORCES ACTING ON THE WALL.

CASE III, EARTHQUAKE LOADING: LOADING CASE I WITH THE ADDITION OF LATERAL EARTHQUAKE FORCES.


CONTROL HOUSE
Aluminum railing
Bridge
Outlet Works
Existing ground surface
Spillway
Crest
Elevation
Assumed rock surface
Copper water stops
Excavate to sound rock
Line drilling
OPERATING GALLERY
SECTION
SCALE 1" = 10'
Do not chamfer curved spillway surfaces
Note: Grout water stops a minimum of 8" into the foundation
Point with two coats of bituminous mastic
Filled with Elastite or approved equal
CONTRACTION JOINT
WITH COPPER WATER STOP
CONSTRUCTION JOINT
DUMMY JOINT
CONTRACTION JOINT "A"

SPILLWAY

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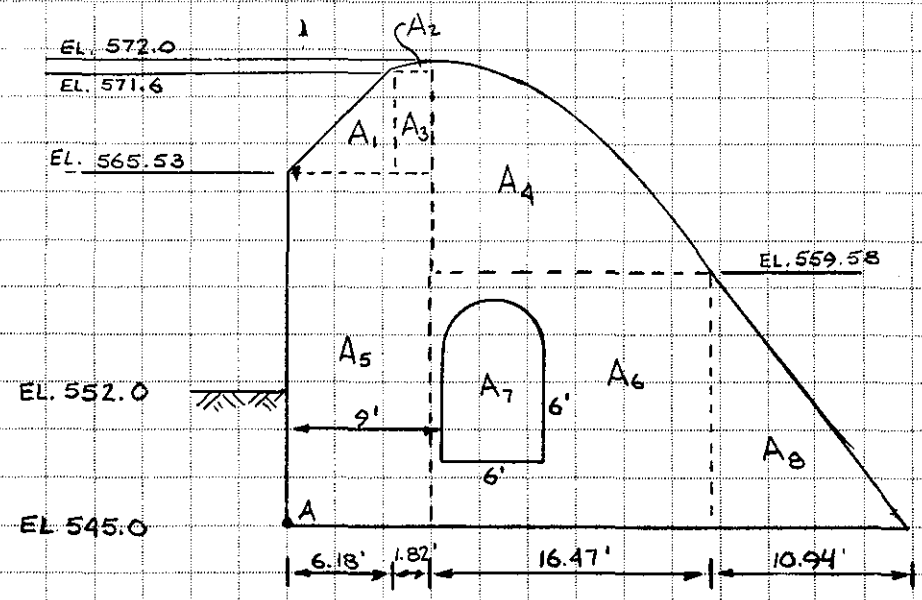
JOB: WESTVILLE DAM STABILITY ANALYSIS
SHEET NO. 1a OF
CALCULATED BY: JMS DATE: 10/19/87
CHECKED BY: LFV DATE: 1/27/88
SCALE

SPILLWAY STABILITY

SECTION ①



$\gamma_{CONC.} = 0.15\ ^{K}/_{CF}$

CONCRETE SECTION - MOMENTS ABOUT POINT A

	AREA (FT^2)	WT (KIP/FT)	ARM (FT)	MOMENT (FT-KIP)
A_1	$\frac{1}{2}(6.18)(6.07) = 18.76$	2.81	$\frac{2}{3}(6.18) = 4.12$	11.58
A_2	APPROX. $\frac{1}{4}$ ELLIPSE $\frac{1}{4}(\pi)(0.4)(1.82) = 0.57$	0.09	$6.18 + (1.82 - \frac{4(1.82)}{3\pi}) = 7.23$	0.65
A_3	$(1.82)(6.07) = 11.05$	1.66	$6.18 + \frac{1}{2}(1.82) = 7.09$	11.77
A_4	APPROX. $\frac{1}{2}$ PARABOLA $\frac{2}{3}(16.47)(12.42) = 136.37$	20.46	$8 + \frac{3}{8}(16.47) = 14.18$	290.12
A_5	$(8)(20.53) = 164.24$	24.64	$\frac{1}{2}(8) = 4$	98.56
A_6	$(16.47)(14.58) = 240.13$	36.02	$8 + \frac{1}{2}(16.47) = 16.24$	584.96
A_7	$(6)(6) + \frac{1}{2}(\pi)(3)^2 = 50.14$	-7.52	$9 + \frac{1}{2}(6) = 12$	-90.24
A_8	$\frac{1}{2}(10.94)(14.58) = 79.76$	11.96	$24.47 + \frac{1}{3}(10.94) = 28.12$	336.32
		90.12^K		$1243.72^{'K}$

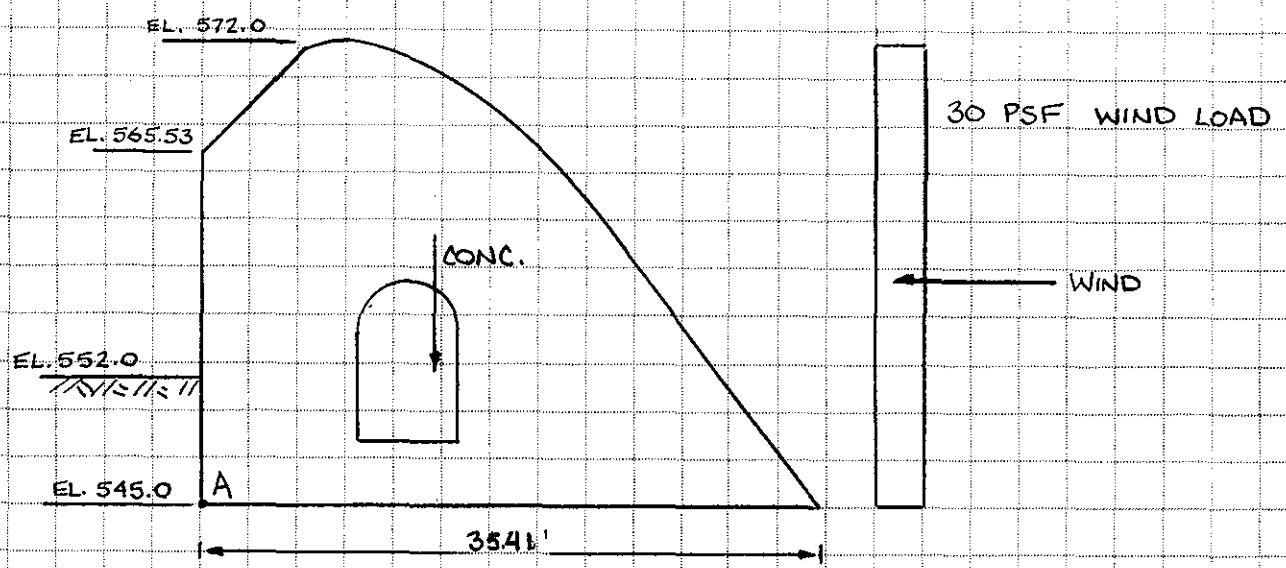
PRODUCT 204-1 NEBS Inc., Groton, Mass. 01471.

SPILLWAY STABILITY (CONT.)

SECTION ①

LOADING CONDITION CASE I - CONSTRUCTION CONDITION

CHECK OVERTURNING - REF. EM 1110-2-2200, CHAP. 3-03



(+) ABOUT A

ITEM	FORCE (K)	ARM (FT)	MOMENT (FT-K)
CONC	90.12 ↓		+1243.72
WIND	(0.03 KSF) × 27 FT = 0.81 ←	27/2 = 13.5	-10.94
	ΣV = 90.12 K , ΣH = 0.81 K		+1232.78 '-K

$\Sigma M / \Sigma V = 1232.78 / 90.12 = 13.68'$

11.80' < 13.68' < 23.6' (OK)
RESULTANT WITHIN MIDDLE THIRD OF BASE
(EM 1110-2-2200, PG. 8)

SPILLWAY STABILITY (CONT.)

SECTION ①

LOADING CONDITION CASE I (CONT.)

CHECK SLIDING - REF. ETL 1110-2-256

USE ALTERNATE METHOD OF ANALYSIS ℙ 2b.

$$FS = \frac{CA + (V-U)\tan\phi}{H}$$

WHERE $C = 80$ PSI (ACI 1983 17.5.2.1)

$\phi = 26.56°$ (BASED ON CONSERVATIVE COEFF. OF FRICTION = 0.5)

AT CONCRETE-ROCK INTERFACE

$$FS = \frac{(80\ \text{PSI})(35.41\ \text{FT}^2)(144\ \text{IN}^2/\text{FT}^2) + (90120\ \#/\text{FT}\ 0)\tan 26.56°}{810\ \#/\text{FT}}$$

$FS = 5.59$

5.59, >> 2 (OK)

(ETL 1110-2-256, PG. 20)

CHECK BEARING PRESSURE

$$f = \frac{P}{A} \pm \frac{Mc}{I}$$

$$f = \frac{90.12\ \text{K/FT}}{35.41\ \text{FT}} \pm \frac{90.12\ \text{K/FT}\,(13.68 - 17.71)(17.71)}{\frac{1}{12}(35.41)^3}$$

$= 2.55$ KSF $\pm$ 1.74 KSF

$f_{UPSTREAM} = 4.29$ KSF

(OK) (ALLOWABLE BEARING PRESSURE = 40 KSF)

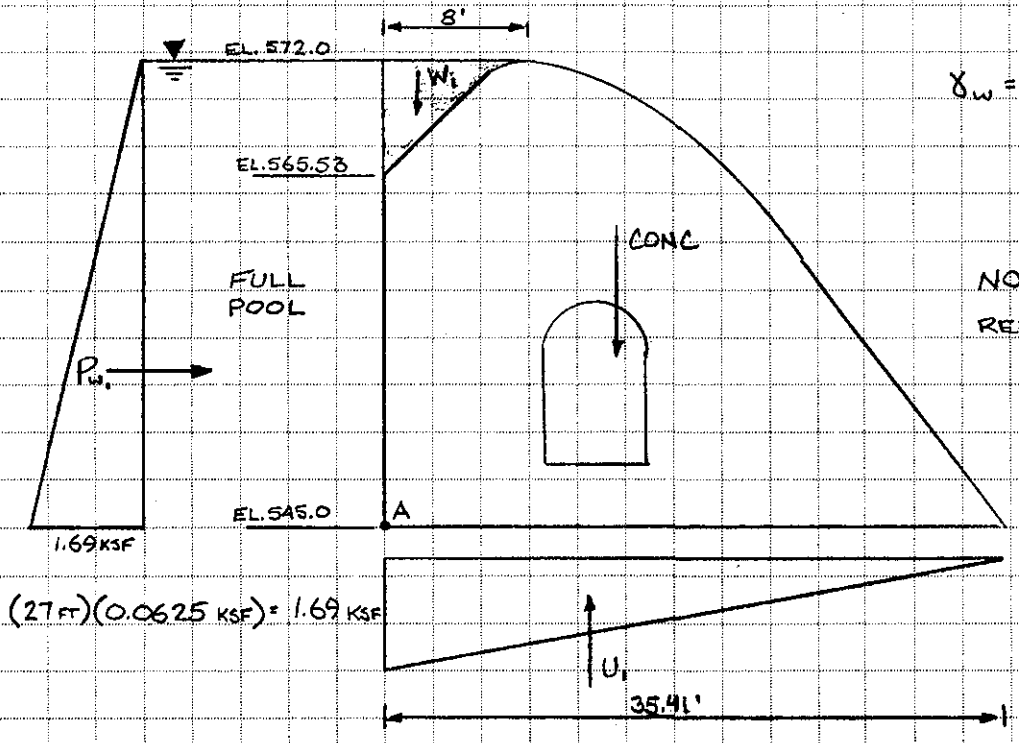
$f_{DOWNSTREAM} = 0.81$ KSF

SPILLWAY STABILITY (CONT.)

SECTION ①

LOADING CONDITION CASE II - NORMAL OPERATING CONDITIONS

CHECK OVERTURNING - REF. EM 1110-2-2200, CHAP 3-03



$\gamma_w = 0.0625$ KCF

NO TAILWATER
REF. DESIGN MEMORANDUM
NO. 6, PG. 12

(+) ABOUT A

ITEM	FORCE (K/FT)	ARM (FT)	MOMENT (FT-K/FT)
CONC	90.12 ↓		1243.72
W_1	$\frac{1}{2}(8)(6.47)(0.0625) = 1.62$ ↓	$\frac{1}{3}(8) = 2.67$	4.33
U_1	$\frac{1}{2}(1.69)(35.41) = 29.92$ ↑	$\frac{1}{3}(35.41) = 11.80$	-353.06
P_{w_1}	$\frac{1}{2}(1.69)(27) = 22.82$ →	$\frac{1}{3}(27) = 9.00$	205.38
	$\Sigma V = 61.82$ K/FT, $\Sigma H = 22.82$ K/FT		1100.37 FT-K/FT

$\Sigma M / \Sigma V = 1100.37 / 61.82 = 17.80'$

$11.80' < 17.80' < 23.60'$ (OK)

RESULTANT WITHIN MIDDLE THIRD OF BASE
(EM 1110-2-2200, PG. 8)

SPILLWAY STABILITY (CONT.)

SECTION ①

LOADING CONDITION CASE II (CONT.)

CHECK SLIDING - REF. ETL 1110-2-256

USE ALTERNATIVE METHOD OF ANALYSIS #2b.

$$FS = \frac{(80\ PSI)(3541\ FT^2)(144\ IN/FT^2) + (61820\ \#/FT)\ TAN\ 26.56^\circ}{22820\ \#/FT}$$

$FS = 19.23 > 2$ OK

(ETL 1110-2-256, PG. 20)

CHECK BEARING PRESSURE

$$f = \frac{61.82\ K/FT}{35.41} \pm \frac{61.82(17.80 - 17.71)(17.71)}{\frac{1}{12}(35.41)^3}$$

$= 1.75\ KSF \pm 0.03\ KSF$

$f_{UPSTREAM} = 1.72\ KSF$

OK (ALLOWABLE BEARING PRESSURE = 40 KSF)

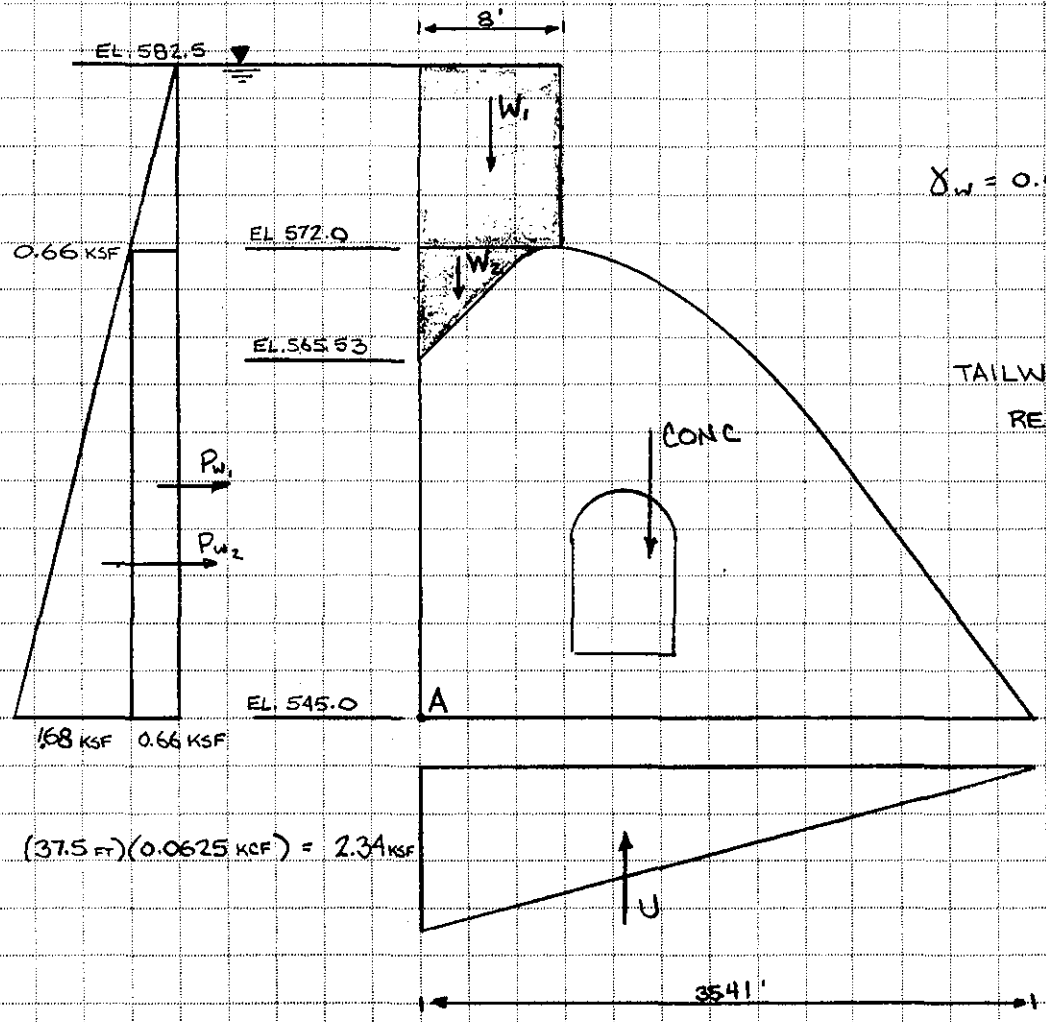
$f_{DOWNSTREAM} = 1.78\ KSF$

SPILLWAY STABILITY (CONT.)

SECTION 1

LOADING CONDITION CASE IV - FLOOD DISCHARGE CONDITION

CHECK OVERTURNING - REF. EM 1110-2-2200, CHAP. 3-03



$\gamma_w = 0.0625$ KCF

TAILWATER BELOW EL. 545.0
REF. DESIGN MEMORANDUM No. 6

SPILLWAY STABILITY (CONT.)

SECTION ①

LOADING CONDITION CASE IV (CONT.)

CHECK OVERTURNING (CONT.)

ITEM	FORCE (K/FT)	ARM (FT)	↻ ABOUT A MOMENT (FT-K/FT)
CONC	90.12 ↓		1243.72
W_1	(8)(10.5)(0.0625) = 5.25 ↓	½(8) = 4.00	21.00
W_2	½(8)(6.47)(0.0625) = 1.62 ↓	⅓(8) = 2.67	4.33
U	½(2.34)(35.41) = 41.43 ↑	⅓(35.41) = 11.80	-489.00
P_{W_1}	(0.66)(27) = 17.82 →	½(27) = 13.50	240.57
P_{W_2}	½(1.68)(27) = 22.68 →	⅓(27) = 9.00	204.12
	ΣV = 56.56 K/FT, ΣH = 40.50 K/FT		1224.74 FT-K/FT

$\Sigma M / \Sigma V = \frac{1224.74}{55.56} = 22.04'$

11.80' < 22.04' < 23.60' OK

RESULTANT WITHIN MIDDLE THIRD OF BASE

(EM 1110-2-2200, PG. 8)

CHECK SLIDING - REF. ETL 1110-2-256

USE ALTERNATE METHOD OF ANALYSIS #2b.

$$FS = \frac{(80\,PSI)(35.41\,FT)(144\,IN^2/FT^2) + (55560\,\#/FT)\tan 26.56^\circ}{40500\,\#/FT}$$

FS = 10.76 > 2 OK (ETL 1110-2-256, PG. 20)

SPILLWAY STABILITY (CONT.)

SECTION 1

LOADING CONDITION CASE IV (CONT.)

CHECK BEARING PRESSURE

$$f = \frac{55.56\ ^{K}/_{FT}}{35.41} \pm \frac{55.56\ ^{K}/_{FT}\,(22.04' - 17.71')(17.71')}{\frac{1}{12}(35.41')^3}$$

$$= 1.57\ \text{KSF} \pm 1.15\ \text{KSF}$$

$f_{UPSTREAM} = 0.42$ KSF

OK (ALLOWABLE BEARING PRESSURE = 40 KSF)

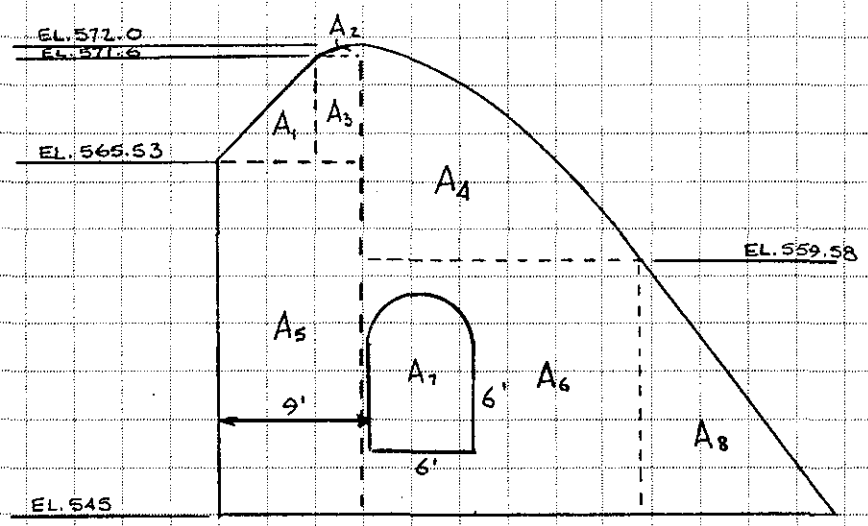
$f_{DOWNSTREAM} = 2.72$ KSF

SPILLWAY STABILITY (CONT.)

SECTION 1

LOADING CONDITION CASE V - CONSTRUCTION CONDITION WITH EARTHQUAKE - REF EM 1110-2-2200, PG. 4b, 5

CHECK OVERTURNING - REF EM 1110-2-2200, CHAP. 3-03



SECTION	AREA (FT²)	DISTANCE TO BASE (Y)(FT)	AY (FT³)
A_1	18.76	22.55	423.04
A_2	0.57	26.77	15.26
A_3	11.05	23.57	260.45
A_4	136.37	19.24	2623.76
A_5	164.24	10.27	1686.74
A_6	240.13	7.29	1750.55
A_7	-50.14	$\frac{(6)(6)(3)+\frac{1}{2}\pi(3)^2(7.27)}{50.14}+4=8.20$	-411.15
A_8	79.76	4.86	387.63
	600.74 FT²		6736.28 FT³

SPILLWAY STABILITY (CONT.)

SECTION ①

LOADING CONDITION CASE V (CONT.)

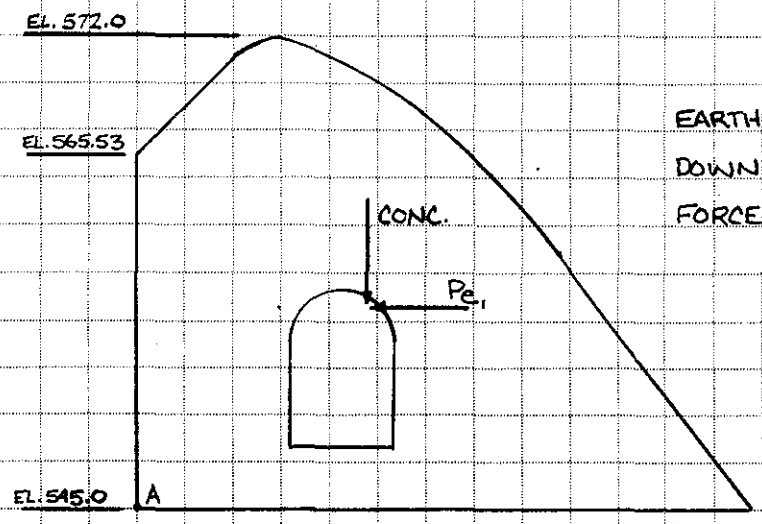
CHECK OVERTURNING (CONT.)

$$\frac{A_Y}{A} = \frac{6736.28}{600.74} = 11.21'$$

EARTHQUAKE FORCE REQUIRED TO ACCELERATE SECTION

$P_{e_1} = \alpha W$ $\alpha = 0.10$ (ER 1110-2-1806, PG. 2)

$P_{e_1} = 0.10(90.12) = 9.01^K$



EARTHQUAKE ACCELERATION IN A DOWNSTREAM DIRECTION. INERTIA FORCES IN A UPSTREAM DIRECTION.

(+) ABOUT A

ITEM	FORCE (K/FT)	ARM (FT)	MOMENT (FT-K/FT)
CONC	90.12 ↓		1243.72
P_{e_1}	9.01 ←	11.21	-101.00
	$\Sigma V = 90.12^{K/FT}$, $\Sigma H = 9.01^{K/FT}$		1142.72 FT-K/FT

$\Sigma M / \Sigma V = 1142.72 / 90.12 = 12.68'$ $11.8' < 12.68' < 23.6'$ (OK)

RESULTANT WITHIN MIDDLE THIRD
(EM 1110-2-2200, PG. 8)

SPILLWAY STABILITY (CONT.)

SECTION ①

LOADING CONDITION CASE IV (CONT.)

CHECK SLIDING - REF ETL 1110-2-256

$$FS = \frac{(80\ PSI)(35.41\ FT)(144\ IN^2/FT^2) + (90120\ \#/FT)\tan 26.56^\circ}{9010\ \#/FT}$$

$FS = 50.28 >> 1.3$ OK (ETL 1110-2-256, PG. 20)

CHECK BEARING PRESSURE

$$f = \frac{90.12\ K/FT}{35.41\ FT} \pm \frac{(90.12\ K/FT)(12.68 - 17.71)(17.71)}{\frac{1}{12}(35.41)^3}$$

$= 2.55\ KSF \pm 2.16\ KSF$

$f_{UPSTREAM} = 4.71\ KSF$

OK (ALLOWABLE BEARING PRESSURE = 40 KSF)

$f_{DOWNSTREAM} = 0.39\ KSF$

SPILLWAY STABILITY (CONT.)

SECTION ①

LOADING CONDITION CASE VI - NORMAL OPERATING CONDITION WITH EARTHQUAKE

CHECK OVERTURNING - REF. EM 1110-2-2200, CHAP. 3-03

EARTHQUAKE INERTIA OF RESERVIOR WATER (EM 1110-2-2200 PG. 4b, 5)

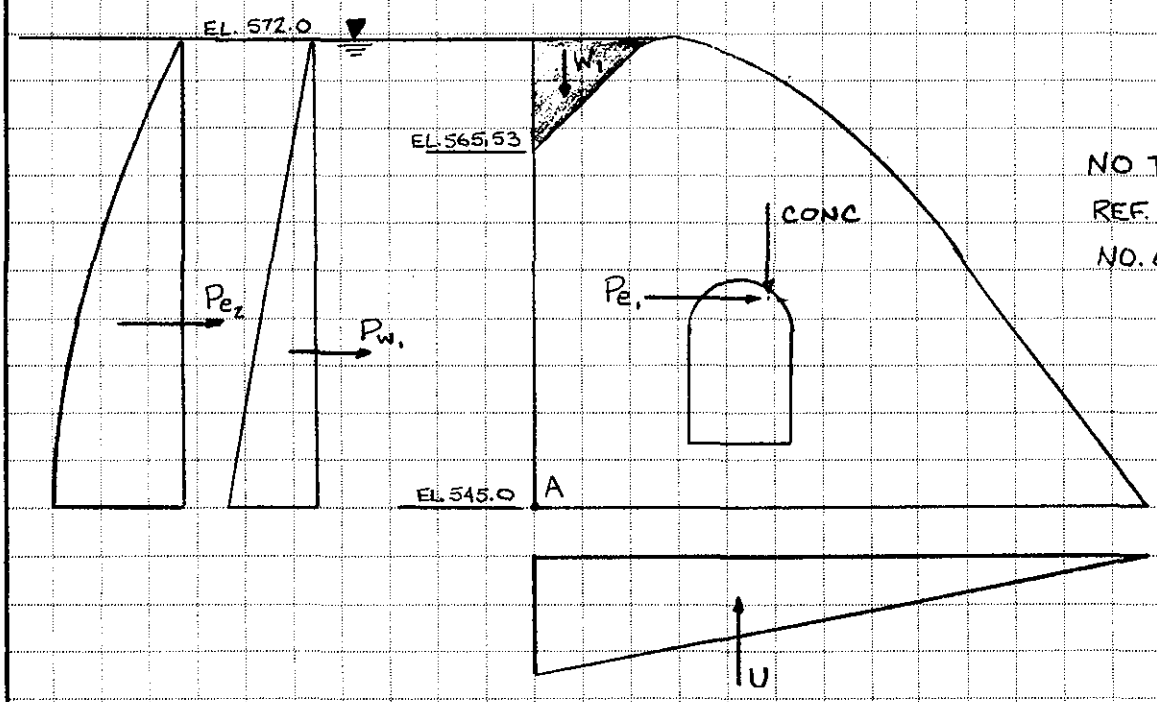
$P_{e_2} = \frac{2}{3} C_e \alpha \gamma \sqrt{h\gamma}$ $\alpha = 0.10$ (ER 1110-2-1806, PG. 2)

$C_e = \frac{51}{\sqrt{1-0.72\left(\frac{h}{1000 t_e}\right)^2}} = \frac{51}{\sqrt{1-0.72\left(\frac{27}{1000(1)}\right)^2}}$

$C_e = 51.01$ (EM 1110-2-2200, PG. 5)

$P_{e_2} = \frac{2}{3}(51.01)(0.10)(27)\sqrt{27 \times 27}$

$= 2479$ lb ACTING @ $0.4(h) = 0.4(27) = 10.8'$ FROM BASE



NO TAILWATER
REF. DESIGN MEMORANDUM NO. 6, PG. 12

SEE CASES II & V FOR CALCULATION OF FORCES AND MOMENT ARMS.

SPILLWAY STABILITY (CONT.)

SECTION ①

LOADING CONDITION CASE VI (CONT.)

CHECK OVERTURNING (CONT.)

(+) ABOUT A

ITEM	FORCE (K/FT)	ARM (FT)	MOMENT (FT-K/FT)
CONC	90.12 ↓		1243.72
W_1	1.62 ↓	2.67	4.33
U	29.92 ↑	11.80	-353.16
P_{w_1}	22.82 →	9.00	205.38
P_{e_1}	9.01 →	11.21	101.00
P_{e_2}	2.48 →	10.80	26.78
	$\Sigma V = 61.82$ K/FT $\Sigma H = 34.40$ K/FT		1026.05 FT-K/FT

$\Sigma M / \Sigma V = 16.6$ 11.8' < 16.6' < 23.6' (OK)

RESULTANT WITHIN MIDDLE THIRD

(EM 1110-2-2200, PG. 8)

CHECK SLIDING - REF. ETL 1110-2-256

$$FS = \frac{(80\ PSI)(354.1\ FT)(144\ IN^2/FT^2) + (61820\ \#/FT)\tan 26.56°}{34400}$$

FS = 12.76 > 1.3 (OK) (ETL 1110-2-256, PG. 20)

SPILLWAY STABILITY (CONT.)

SECTION 1

LOADING CONDITION VI (CONT.)

CHECK BEARING PRESSURE

$$f = \frac{61.82^{K/FT}}{35.41} \pm \frac{(61.82^{K/FT})(16.6' - 17.71')(17.71')}{\frac{1}{12}(35.41')^3}$$

$$= 1.75 \pm 0.33 \text{ KSF}$$

$f_{UPSTREAM} = 2.08$ KSF

OK ($F_{ALLOW} = 40$ KSF)

$f_{DOWNSTREAM} = 1.42$ KSF

STORCH ENGINEERS
STORCH ASSOCIATES
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Landscape Architects - Environmental Specialists

JOB WESTVILLE DAM STABILITY ANALYSIS
SHEET NO. 15 OF
CALCULATED BY JMS DATE 10/19/87
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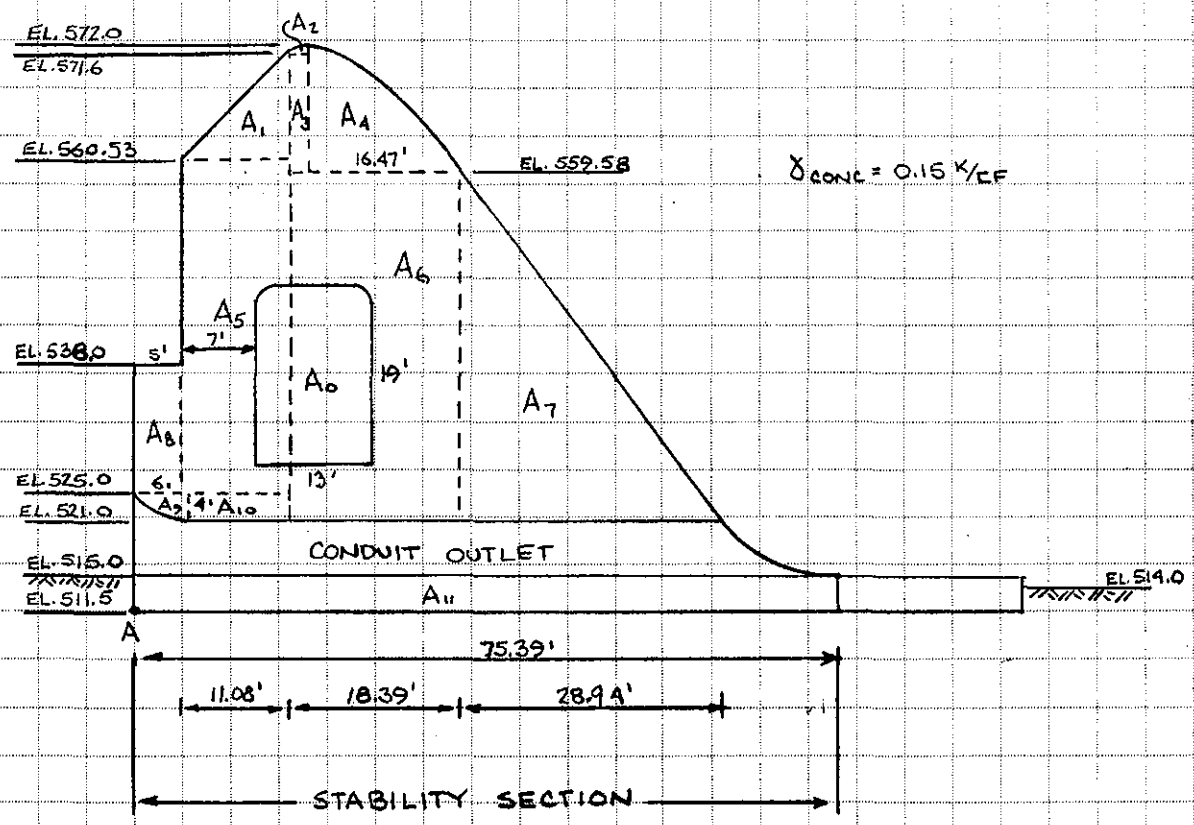
SCALE

SPILLWAY STABILITY (CONT.)

SECTION 2



SPILLWAY STABILITY (CONT.)

SECTION ②

CONCRETE SECTION MOMENTS ABOUT POINT A

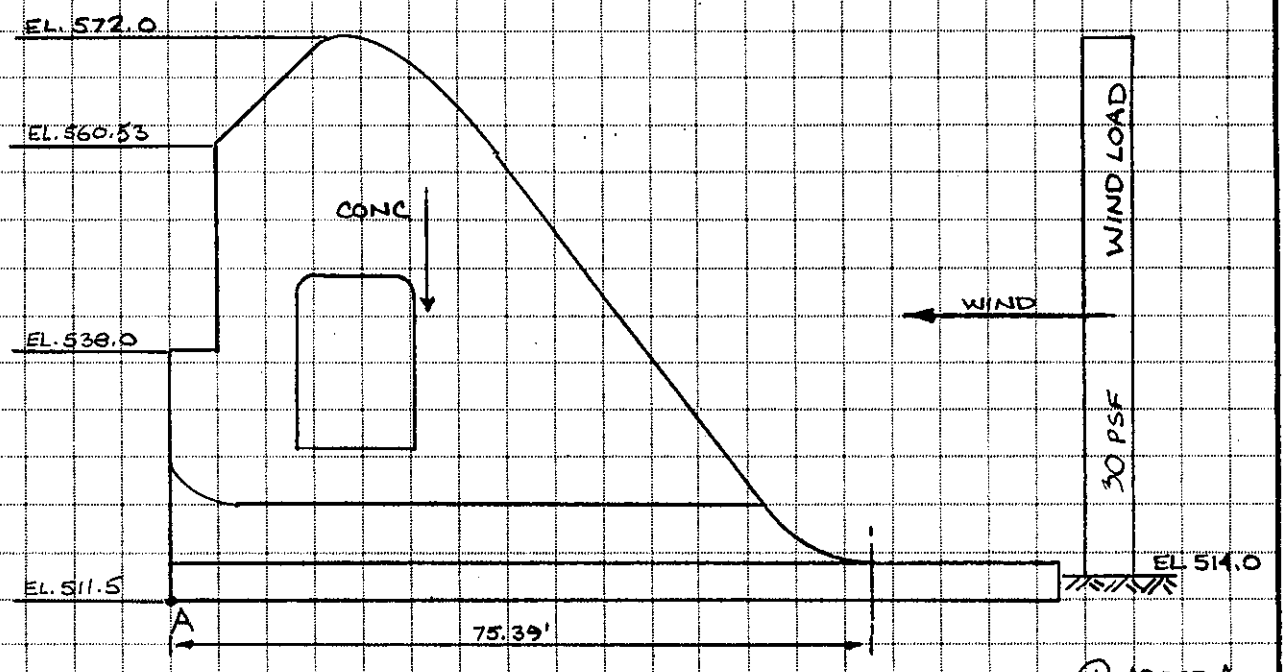
	AREA (FT^2)	WT (K/FT)	ARM (FT)	MOMENT ($FT-K/FT$)
A_1	$\frac{1}{2}(11.08)(11.08) = 61.38$	9.21	$\frac{2}{3}(11.08)+5 = 12.39$	114.11
A_2	APPROX. $\frac{1}{4}$ ELLIPSE $\frac{1}{4}(\pi)(1.92)(0.4) = 0.60$	0.09	$16.08+\left(1.92-\frac{4(1.92)}{3\pi}\right) = 17.19$	1.55
A_3	$(1.92)(12.02) = 23.08$	3.46	$16.08+\frac{1}{2}(1.92) = 17.04$	58.96
A_4	APPROX $\frac{1}{2}$ PARABOLA $\frac{2}{3}(16.47)(12.42) = 136.37$	20.46	$18.00+\frac{3}{8}(16.47) = 24.18$	494.65
A_5	$(11.08)(35.53) = 393.67$	59.05	$5.00+\frac{1}{2}(11.08) = 10.54$	622.39
A_6	$(18.39)(38.58) = 709.49$	106.42	$16.08+\frac{1}{2}(18.39) = 25.28$	2690.30
A_7	$\frac{1}{2}(28.94)(38.58) = 558.25$	83.74	$34.47+\frac{1}{3}(28.94) = 44.12$	3694.61
A_8	$(5)(13) = 65.00$	9.75	$\frac{1}{2}(5) = 2.50$	24.38
A_9	APPROX $\frac{1}{4}$ ELLIPSE $\frac{1}{4}(\pi)(4)(6) = 18.85$	2.83	$5-\frac{4(5)}{3\pi} = 2.88$	8.15
A_{10}	$(4)(10.08) = 40.32$	6.05	$6+\frac{1}{2}(10.08) = 11.04$	66.79
A_{11}	$(3.5)(75.39) = 263.87$	39.58	$\frac{1}{2}(75.39) = 37.70$	1492.17
A_0	$(13)(19) = 247.00$	-37.05	$12+\frac{1}{2}(13) = 18.5$	-685.43
		303.59 K/FT		8582.63 FT·K/FT

SPILLWAY STABILITY (CONT.)

SECTION ②

LOADING CONDITION CASE I - CONSTRUCTION CONDITION

CHECK OVERTURNING - REF. EM 1110-2-2200, CHAP 3-03



↻+ ABOUT A

ITEM	FORCE (K/FT)	ARM (FT)	MOMENT (FT-K/FT)
CONC	303.59 ↓		8582.63
WIND	(0.03)(58) = 1.74 ←	2.5 + 58/2 = 31.50	- 54.81
	ΣV = 303.59 K/FT, ΣH = 1.74 K/FT		8527.82 FT-K/FT

$\Sigma M / \Sigma V = 8527.82 / 303.59 = 28.09'$

25.13' < 28.09' < 50.26' (OK)

RESULTANT WITHIN MIDDLE THIRD OF BASE (EM 1110-2-2200, PG. 8)

SPILLWAY STABILITY (CONT.)

SECTION ②

LOADING CONDITION CASE I (CONT.)

CHECK SLIDING - REF. ETL 1110-2-256

USE ALTERNATE METHOD OF ANALYSIS #2b.

$$FS = \frac{cA + (V-U)\tan\phi}{H}$$

WHERE $c = 80$ psi (ACI 1983 17.5.2.1)

$\phi = 26.56°$ (BASED ON CONSERVATIVE COEFF. OF FRICTION = 0.5)

AT CONCRETE-ROCK INTERFACE

$$FS = \frac{(80\text{ psi})(75.39\text{ ft})(144\text{ in}^2/\text{ft}^2) + (303590\text{ \#/ft})\tan 26.56°}{1740\text{ \#/ft}}$$

$FS = 586$

$586 >> 2$ OK (ETL 1110-2-256, PG. 20)

CHECK BEARING PRESSURE

$$f = \frac{P}{A} \pm \frac{Mc}{I}$$

$$f = \frac{303.59\text{ K/ft}}{75.39\text{ ft}} \pm \frac{303.59\text{ K/ft}\,(28.09' - 37.70)(37.70)}{\frac{1}{12}(75.39)^3}$$

$= 4.03$ KSF $\pm$ 3.08 KSF

$f_{UPSTREAM} = 7.11$ KSF

OK ($f_{ALLOW} = 40$ KSF)

$f_{DOWNSTREAM} = 0.95$ KSF

STORCH ENGINEERS
STORCH ASSOCIATES
Engineers - Architects - Surveyors
Landscape Architects - Environmental Specialists

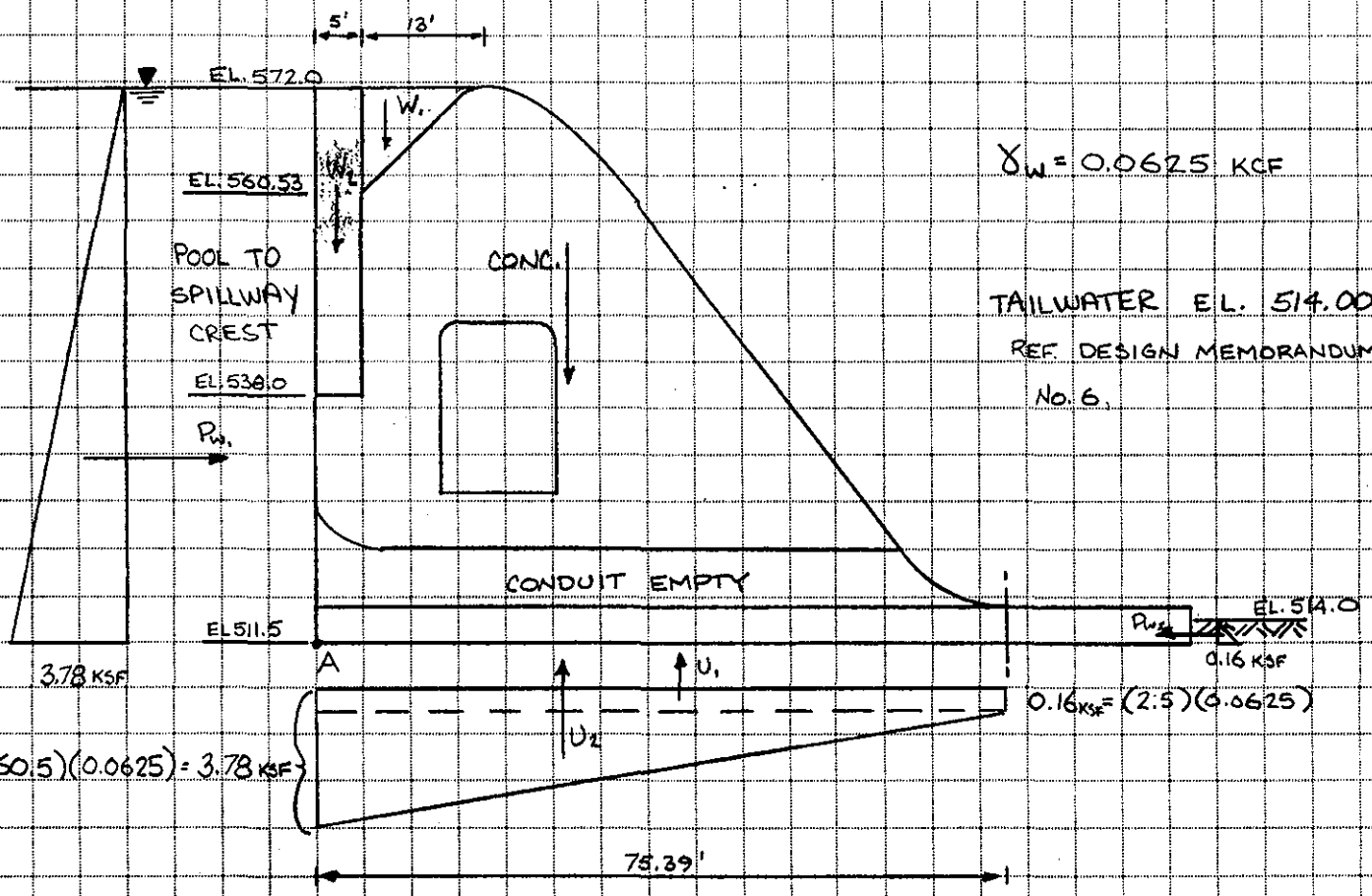
JOB WESTVILLE DAM STABILITY ANALYSIS
SHEET NO. 19 OF
CALCULATED BY JMS DATE 10/21/87
CHECKED BY LFV DATE 1/27/88
SCALE

SPILLWAY STABILITY (CONT.)

SECTION ②

LOADING CONDITION CASE II - NORMAL OPERATING CONDITIONS

CHECK OVERTURNING - REF. EM 1110-2-2200, CHAP. 3-03



PRODUCT 204-1 NEBS Inc., Groton, Mass. 01471.

SPILLWAY STABILITY (CONT)

SECTION ②

LOADING CONDITION CASE II (CONT.)

CHECK OVERTURNING (CONT.)

ITEM	FORCE (K/FT)	ARM (FT)	(+) ABOUT A MOMENT (FT-K/FT)
CONC	303.59 ↓		8582.63
W_1	$\frac{1}{2}(13)(11.67)(0.0625) = 4.74$ ↓	$5 + \frac{1}{3}(13) = 9.33$	44.22
W_2	$(5)(34)(0.0625) = 10.63$ ↓	$\frac{1}{2}(5) = 2.50$	26.58
U_1	$(0.16)(75.39) = 12.06$ ↑	$\frac{1}{2}(75.39) = 37.70$	-454.66
U_2	$\frac{1}{2}(3.78-0.16)(75.39) = 136.46$ ↑	$\frac{1}{3}(75.39) = 25.13$	-3429.24
P_{w_1}	$\frac{1}{2}(3.78)(60.5) = 114.35$ →	$\frac{1}{3}(60.5) = 20.17$	2306.44
P_{w_2}	$\frac{1}{2}(0.16)(2.5) = 0.20$ ←	$\frac{1}{3}(2.5) = 0.83$	-0.17
	$\Sigma V = 170.44$ K/FT, $\Sigma H = 114.15$ K/FT		7075.8 FT-K/FT

$\Sigma M / \Sigma V = 7075.8 / 170.44 = 41.51'$

$25.13' < 41.51' < 50.26'$ (OK)

RESULTANT WITHIN MIDDLE THIRD OF BASE (EM 1110-2-2200, PG. 8)

CHECK SLIDING - REF. ETL 1110-2-256

USE ALTERNATIVE METHOD OF ANALYSIS #2b.

$$FS = \frac{(80\ \text{PSI})(75.39\ \text{FT})(144\ \text{IN}^2/\text{FT}^2) + (170440\ \#/\text{FT})\ \tan 26.56^\circ}{114150\ \#/\text{FT}}$$

$= 8.35$

$8.35 > 2$ (OK) (ETL 1110-2-256, PG. 20)

SPILLWAY STABILITY (CONT.)

SECTION 2

LOADING CONDITION CASE II (CONT.)

CHECK BEARING PRESSURE

$$f = \frac{170.44\ K/FT}{75.39\ FT} \pm \frac{170.44\ K/FT\,(41.51' - 37.70')(37.70')}{\frac{1}{12}(75.39)^3}$$

$$= 2.26\ KSF \pm 0.69\ KSF$$

$f_{UPSTREAM} = 1.57\ KSF$

OK ($f_{ALLOW} = 40\ KSF$)

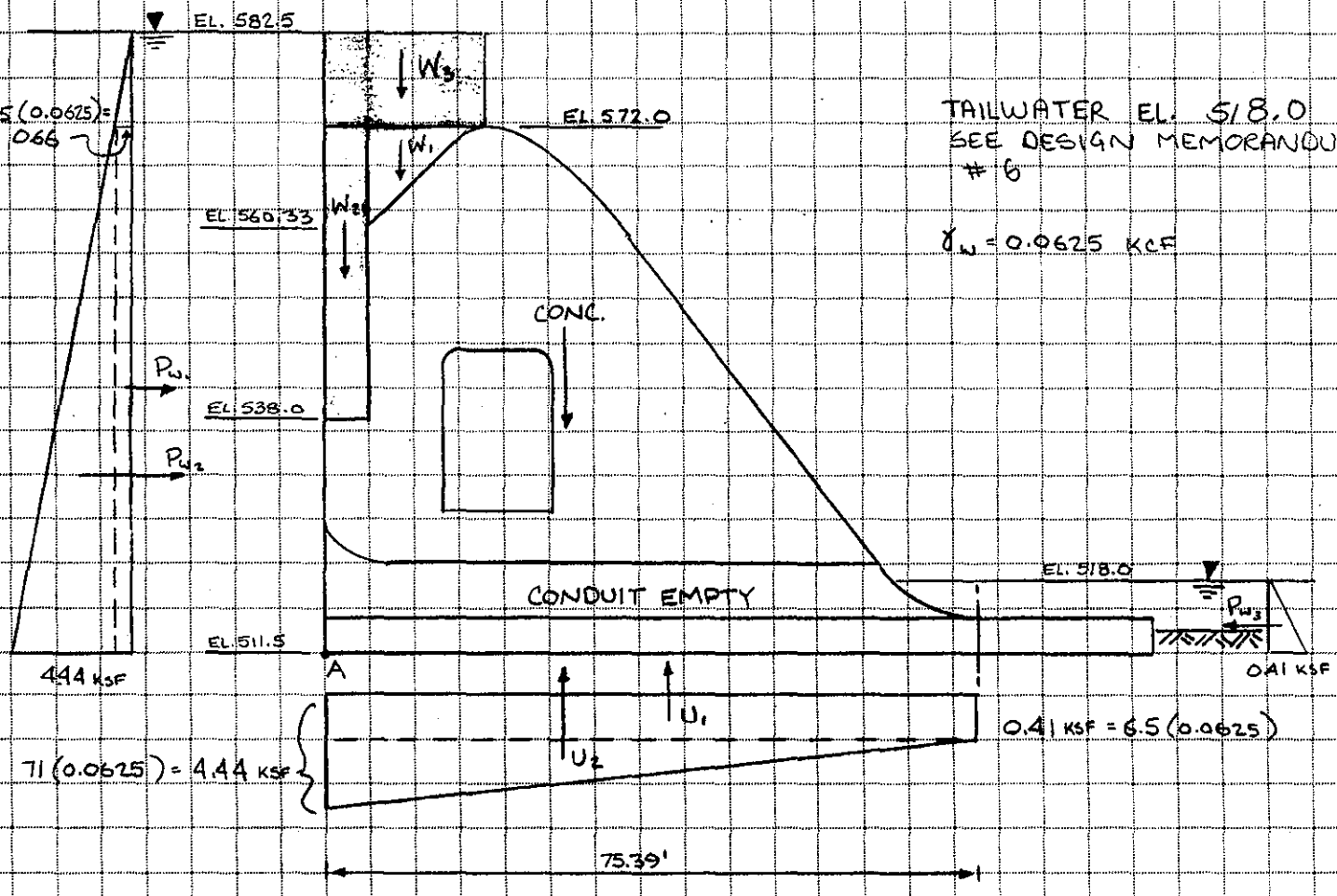
$f_{DOWNSTREAM} = 2.95\ KSF$

SPILLWAY STABILITY (CONT.)

SECTION ②

LOADING CONDITION CASE IV - FLOOD DISCHARGE CONDITION

CHECK OVERTURNING - REF. EM 1110-2-2200, CHAP. 3-03



TAILWATER EL. 518.0
SEE DESIGN MEMORANDUM #6

$\gamma_w = 0.0625$ KCF

SPILLWAY STABILITY (CONT.)

SECTION ②

LOADING CONDITION CASE IV (CONT.)

CHECK OVERTURNING (CONT.)

ITEM	FORCE (K/FT)	ARM (FT)	MOMENT (FT-K/FT)
CONC	303.59 ↓		8582.63
W_1	4.74 ↓	9.33	44.22
W_2	10.63 ↓	2.50	26.58
W_3	(18)(10.5)(0.0625) = 11.81 ↓	$\frac{1}{2}(18) = 9.00$	106.29
U_1	(0.41)(75.39) = 30.91 ↑	$\frac{1}{2}(75.39) = 37.70$	-1165.31
U_2	$\frac{1}{2}(4.44 - 0.41)(75.39) = 151.91$ ↑	$\frac{1}{3}(75.39) = 25.13$	-3817.50
P_{w_1}	(0.66)(60.5) = 39.93 →	$\frac{1}{2}(60.5) = 30.25$	1207.88
P_{w_2}	$\frac{1}{2}(4.44 - 0.66)(60.5) = 114.35$ →	$\frac{1}{3}(60.5) = 20.17$	2306.44
P_{w_3}	$(.60)\frac{1}{2}(0.41)(6.5) = 0.80$ ←	$\frac{1}{3}(3.9) = 1.3$	-1.04
	$\Sigma V = 147.95$ K/FT, $\Sigma H = 153.48$		7290.19 FT-K/FT

$\Sigma M / \Sigma V = 7290.19 / 147.95 = 49.27'$

$25.13' < 49.27' < 50.26'$ (OK)

RESULTANT WITHIN MIDDLE THIRD OF BASE

(EM 1110-2-2200, PG. 8)

SPILLWAY STABILITY (CONT.)

SECTION 2

LOADING CONDITION CASE IV (CONT.)

CHECK SLIDING - REF. ETL 1110-2-256

USE ALTERNATIVE METHOD OF ANALYSIS #2b.

$$FS = \frac{(80\ PSI)(75.39\ FT)(144\ IN^2/FT^2) + (147950\ \#/FT)\ TAN\ 26.56^\circ}{153480\ \#/FT}$$

$FS = 6.14$

$6.14 > 2$ OK (ETL 1110-2-256, PG. 20)

CHECK BEARING PRESSURE

$$F = \frac{147.95\ \#/FT}{75.39\ FT} \pm \frac{147.95\ (49.27 - 37.70)\ 37.70}{\frac{1}{12}(75.39)^3}$$

$= 1.96\ KSF \pm 1.81\ KSF$

$F_{UPSTREAM} = 0.15\ KSF$

OK ($F_{ALLOW} = 40\ KSF$)

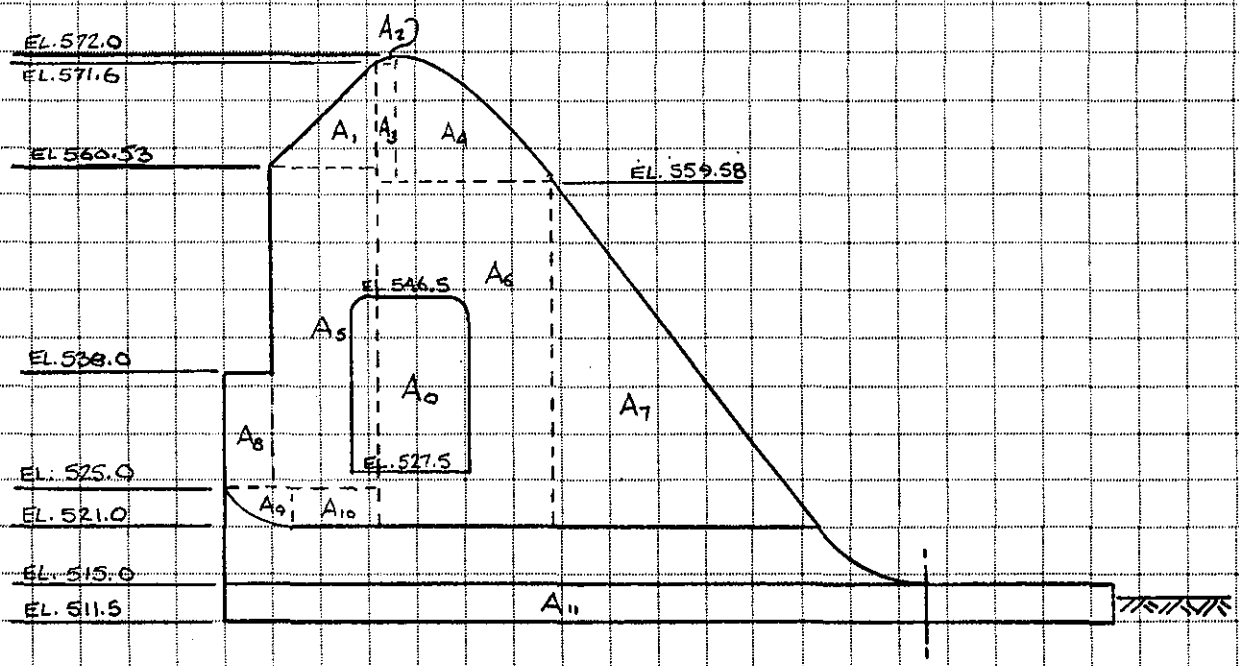
$F_{DOWNSTREAM} = 3.77\ KSF$

SPILLWAY STABILITY (CONT.)

SECTION ②

LOADING CONDITION CASE IV - CONSTRUCTION CONDITION WITH EARTHQUAKE - REF. EM 1110-2-2200, PG. 4b,5

CHECK OVERTURNING - REF. EM 1110-2-2200, CHAP. 3-03



SPILLWAY STABILITY (CONT)

SECTION ②

LOADING CONDITION CASE V (CONT.)

CHECK OVERTURNING (CONT.)

SECTION	AREA (FT^2)	DISTANCE TO BASE (Y) (FT)	AY (FT^3)
A_1	61.38	$49.03 + \frac{1}{3}(11.07) = 52.72$	3235.95
A_2	0.60	$60.10 + \frac{4(0.4)}{3\pi} = 60.25$	36.15
A_3	23.08	$48.08 + \frac{1}{2}(12.02) = 54.09$	1248.40
A_4	136.37	$48.08 + \frac{2}{5}(12.42) = 53.05$	7234.16
A_5	393.67	$13.50 + \frac{1}{2}(35.33) = 31.17$	12270.7
A_6	709.49	$9.50 + \frac{1}{2}(38.58) = 28.79$	20426.22
A_7	558.25	$9.50 + \frac{1}{3}(38.58) = 22.36$	12482.5
A_8	65.00	$13.50 + \frac{1}{2}(13) = 20.00$	1300.00
A_9	18.85	$9.50 + \frac{5}{8}(4) = 12.00$	226.20
A_{10}	40.32	$9.5 + \frac{1}{2}(4) = 11.50$	463.68
A_{11}	263.87	$\frac{1}{2}(3.5) = 1.75$	461.77
A_0	-247.00	$16 + \frac{1}{2}(19) = 25.50$	-6298.5
	2023.9 FT^2		53087.2 FT^3

$$\Sigma AY / \Sigma A = \frac{53087.2}{2023.9} = 26.23'$$

SPILLWAY STABILITY (CONT.)

SECTION 2

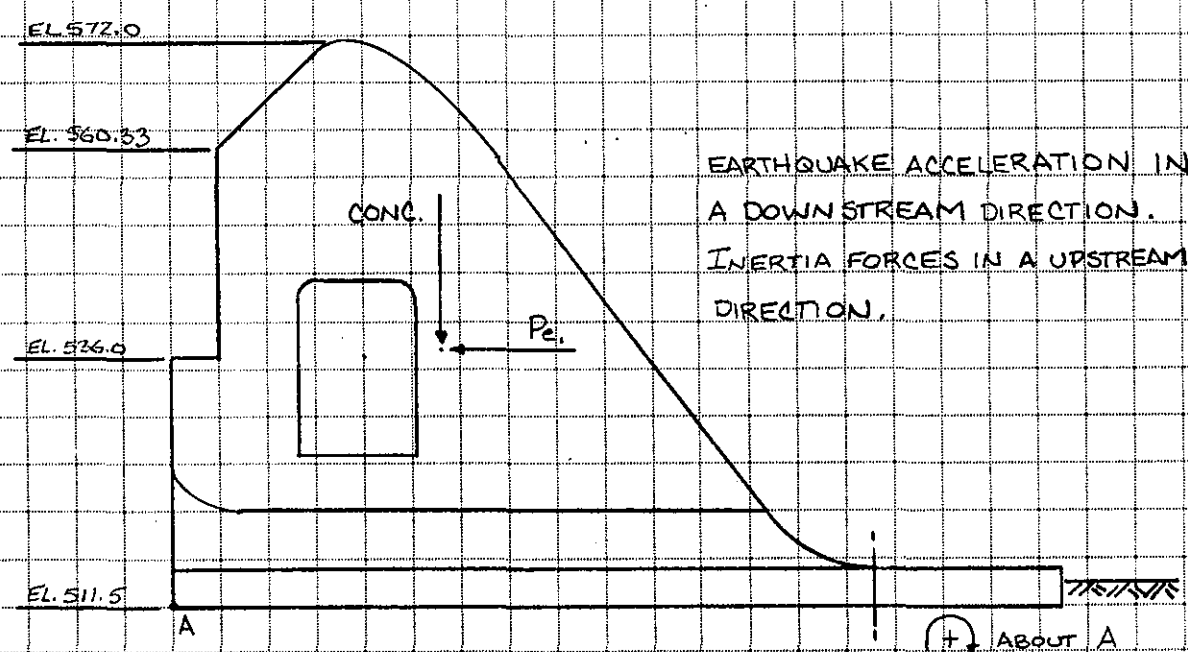
LOADING CONDITION CASE V (CONT)

CHECK OVERTURNING (CONT)

EARTHQUAKE FORCE REQUIRED TO ACCELERATE SECTION

$P_e = \alpha W$ $\alpha = 0.10$ (ER 1110-2-1806, PG.2)

$P_e = 0.10(303.59) = 30.36^K$



EARTHQUAKE ACCELERATION IN A DOWNSTREAM DIRECTION. INERTIA FORCES IN A UPSTREAM DIRECTION.

ITEM	FORCE (K/FT)	ARM (FT)	MOMENT (FT-K/FT)
CONC	303.59 ↓		8582.63
P_{e_1}	30.36 ←	26.23	-796.34
	$\Sigma V = 303.59^K/FT$, $\Sigma H = 30.36^K/FT$		7786.3 FT-K/FT

$\Sigma M / \Sigma V = 7786.3 / 303.59 = 25.65'$

$25.13' < 25.65' < 50.26'$ OK

RESULTANT WITHIN MIDDLE THIRD OF BASE

(EM 1110-2-2200, PG. 8)

SPILLWAY STABILITY (CONT.)

SECTION ②

LOADING CONDITION CASE V (CONT.)

CHECK SLIDING - REF. ETL 1110-2-256

$$FS = \frac{80\,PSI\,(75.39\,FT)(144\,IN^2/FT^2) + (303590\,\#/FT)\,TAN\,26.56^\circ}{30360\,\#/FT}$$

$FS = 33.61 > 1.3$ OK (ETL 1110-2-256, P6.20)

CHECK BEARING PRESSURE

$$f = \frac{303.59\,K/FT}{75.39\,FT} \pm \frac{(303.59\,K/FT)(25.65' - 37.70')(37.70)}{\frac{1}{12}(75.39)^3}$$

$= 4.03\,KSF \pm 3.54\,KSF$

$f_{UPSTREAM} = 7.57\,KSF$

OK ($f_{ALLOW} = 40\,KSF$)

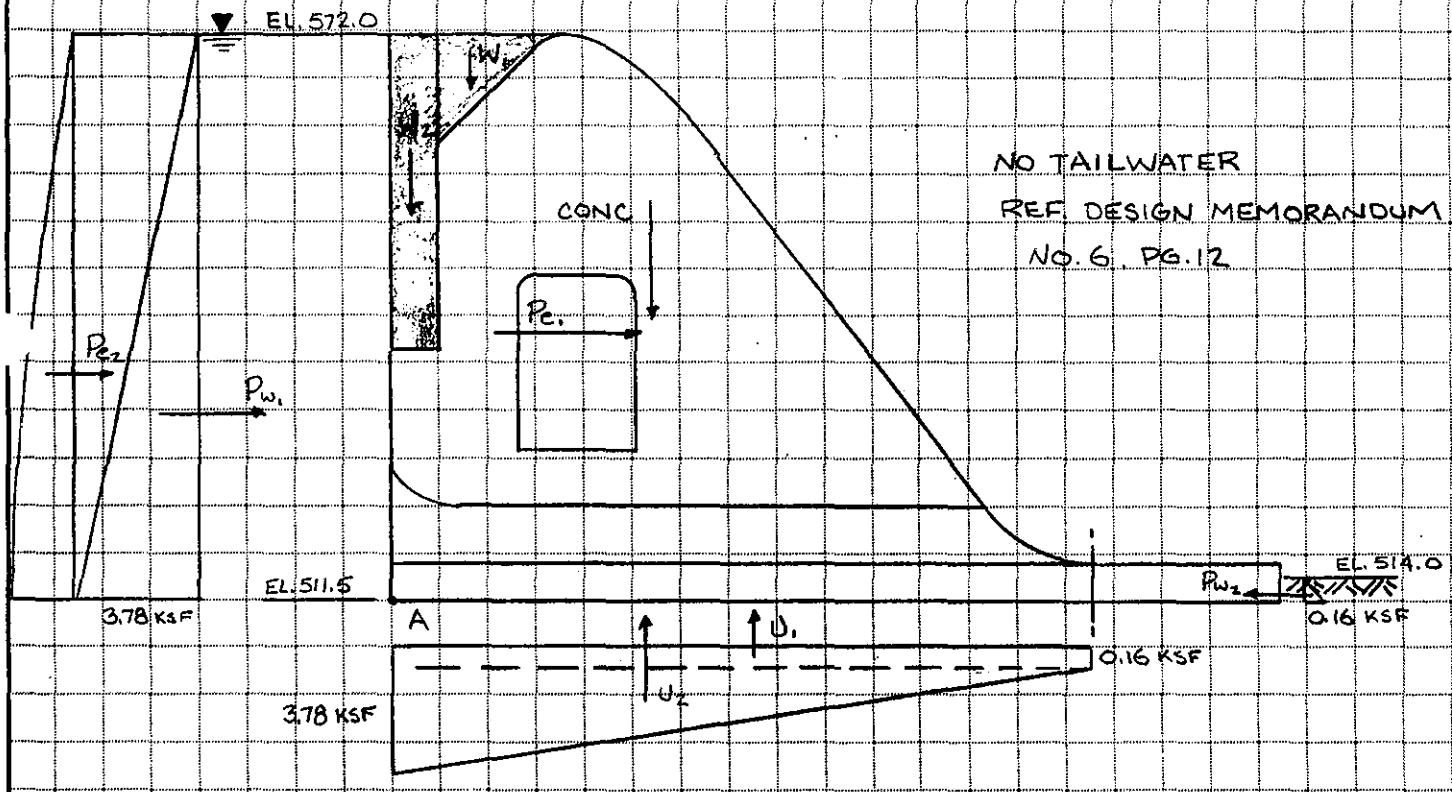
$f_{DOWNSTREAM} = 0.49\,KSF$

SPILLWAY STABILITY (CONT.)

SECTION ②

LOADING CONDITION CASE VI - NORMAL OPERATING CONDITION WITH EARTHQUAKE

CHECK OVERTURNING - REF. EM 1110-2-2200, CHAP. 3-03



NO TAILWATER
REF. DESIGN MEMORANDUM
NO. 6, PG. 12

SEE CASES II & V FOR CALCULATION OF FORCES AND MOMENT ARMS

EARTHQUAKE INERTIA OF RESERVIOR WATER (EM 1110-2-2200, PG. 4b,5)

$$P_{e_2} = \frac{2}{3} C_e \alpha \gamma \sqrt{h \gamma}$$

$\alpha = 0.10$ (ER 1110-2-1806, PG. 2)

$$C_e = \frac{51}{\sqrt{1 - 0.72\left(\frac{60.5}{7000}\right)^2}} = 51.07$$

$$P_{e_2} = \frac{2}{3}(51.07)(0.10)(60.5)(60.5)$$

$= 12462$ lb ACTING @ $0.4(h) = 24.2'$ FROM BASE

SPILLWAY STABILITY (CONT.)

SECTION ②

LOADING CONDITION CASE VI (CONT.)

CHECK OVERTURNING (CONT.)

ITEM	FORCE (K/FT)	ARM (FT)	(+) ABOUT A MOMENT (FT-K/FT)
CONC	303.59 ↓		8582.63
W_1	4.74 ↓	9.33	44.22
W_2	10.63 ↓	2.50	26.58
U_1	12.06 ↑	37.70	-454.66
U_2	136.46 ↑	25.13	-3429.24
P_{w_1}	114.35 →	20.17	2306.44
P_{e_1}	30.36 →	26.03	796.34
P_{e_2}	12.46 →	24.20	301.53
P_{w_3}	0.20 ←	0.83	-0.17
	$\Sigma V = 170.44$ K/FT, $\Sigma H = 156.97$ K/FT		8173.67 FT-K/FT

$$\Sigma M / \Sigma V = 8173.67 / 170.44 = 47.96'$$

$25.13' < 47.96' < 50.26'$ OK

RESULTANT WITHIN MIDDLE THIRD OF BASE

(EM 1110-2-2200, PG. 8)

SPILLWAY STABILITY (CONT.)

SECTION 2

LOADING CONDITION CASE VI (CONT.)

CHECK SLIDING - REF. ETL 1110-2-256

$$FS = \frac{80\ \text{psi}\,(75.39\ \text{FT})(144\ \text{IN}^2/\text{FT}^2) + (170440\ \#/\text{FT})(\tan 26.56^\circ)}{156970\ \#/\text{FT}}$$

$FS = 6.08 > 1.3$ OK (ETL 1110-2-256, PG. 20)

CHECK BEARING PRESSURE

$$F = \frac{170.44\ \text{K/FT}}{75.39\ \text{FT}} \pm \frac{(170.44\ \text{K/FT})(47.96' - 37.70')(37.70')}{\frac{1}{12}(75.39)^3}$$

$= 2.26\ \text{KSF} \pm 1.85\ \text{KSF}$

$F_{UPSTREAM} = 0.41\ \text{KSF}$

OK ($F_{ALLOW} = 40\ \text{KSF}$)

$F_{DOWNSTREAM} = 4.11\ \text{KSF}$

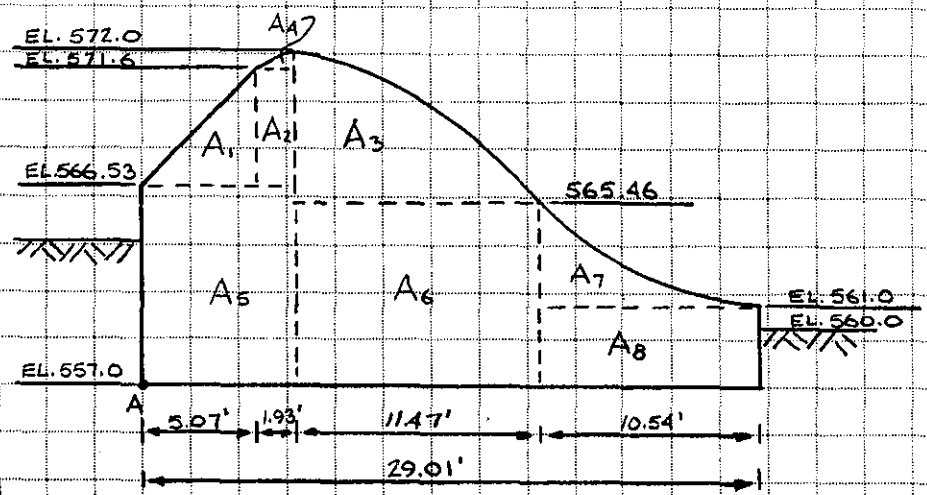
STORCH ENGINEERS
STORCH ASSOCIATES
Engineers - Architects - Surveyors
Landscape Architects - Environmental Specialists

JOB: WESTVILLE DAM STABILITY ANALYSIS
SHEET NO. 32 OF
CALCULATED BY JMS DATE 10/21/87
CHECKED BY LFV DATE 1/27/88
SCALE

SPILLWAY STABILITY (CONT)

SECTION ③

CONCRETE SECTIONS - MOMENT ABOUT A



SECTION	AREA (FT²)	FORCE (K/FT)	ARM (FT)	MOMENT (+)
A_1	$\frac{1}{2}(5.07)(5.07) = 12.85$	1.93	$\frac{2}{3}(5.07) = 3.38$	6.52
A_2	$(1.93)(5.07) = 9.79$	1.47	$5.07 + \frac{1}{2}(1.93) = 6.04$	8.88
A_3	APPROX ½ PARABOLA $\frac{2}{3}(11.47)(6.54) = 50.01$	7.50	$7 + \frac{3}{8}(11.47) = 11.30$	84.75
A_4	APPROX ¼ ELLIPSE $\frac{1}{4}(\pi)(1.93)(0.40) = 0.61$	0.09	$5.07 + \left(1.93 - \frac{4(1.93)}{3\pi}\right) = 6.18$	0.56
A_5	$(7.00)(9.53) = 66.71$	10.01	$\frac{1}{2}(7.00) = 3.50$	35.04
A_6	$(11.47)(8.46) = 97.04$	14.56	$7 + \frac{1}{2}(11.47) = 12.74$	185.49
A_7	$\frac{1}{3}(10.54)(4.46) = 15.67$	2.35	$18.47 + \frac{3}{10}(10.54) = 21.63$	50.83
A_8	$(10.54)(4.00) = 42.16$	6.32	$18.47 + \frac{1}{2}(10.54) = 23.74$	150.04
		44.23 K/FT		522.11 FT-K/FT

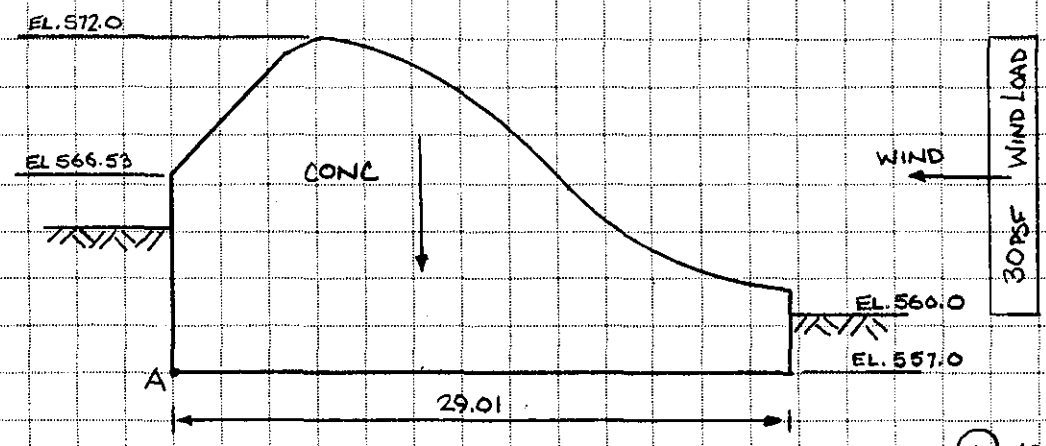
PRODUCT 204-1 NEBS Inc., Groton, Mass. 01471.

SPILLWAY STABILITY (CONT)

SECTION ③

LOADING CONDITION CASE I - CONSTRUCTION CONDITION

CHECK OVERTURNING - REF. EM 1110-2-2200, CHAP. 3-03



(+) ↓ ABOUT A

ITEM	FORCE (K/FT)	ARM (FT)	MOMENT (FT-K/FT)
CONC	44.23		522.11
WIND	(0.03)(12) = 0.36	3 + ½(12) = 9	-3.24
	ΣV = 44.23 K/FT, ΣH = 0.36 K/FT		518.87 FT-K/FT

$$\Sigma M / \Sigma V = \frac{518.87}{44.23} = 11.73'$$

9.67' < 11.73' < 19.34' (OK)

RESULTANT WITHIN MIDDLE THIRD OF BASE

(EM 1110-2-2200, PG. 8)

SPILLWAY STABILITY (CONT.)

SECTION ③

LOADING CONDITION CASE I (CONT.)

CHECK SLIDING - REF. ETL 1110-2-256

$$FS = \frac{cA + (V-U)\tan\phi}{H}$$

WHERE $c = 80$ PSI (ACI 1983 17.5.2.1)
$\phi = 26.56°$ (BASED ON CONSERVATIVE COEFF OF FRICTION = 0.5) AT CONCRETE - ROCK INTERFACE

$$FS = \frac{(80\ \text{PSI})(29.01\ \text{FT})(144\ \text{IN}^2/\text{FT}^2) + (44230\ \#/\text{FT})\tan 26.56°}{360\ \#/\text{FT}}$$

$FS = 990$

$990 >> 2$ OK
(ETL 1110-2-256, PG. 20)

CHECK BEARING PRESSURE

$$f = \frac{P}{A} \pm \frac{Mc}{I}$$

$$f = \frac{44.23\ \text{K/FT}}{29.01\ \text{FT}} \pm \frac{44.23\ \text{K/FT}\,(11.73' - 14.51')(14.51')}{\frac{1}{12}(29.01')^3}$$

$= 1.52\ \text{KSF} \pm 0.87\ \text{KSF}$

$f_{UPSTREAM} = 2.40$ KSF

OK ($f_{ALLOW} = 40$ KSF)

$f_{DOWNSTREAM} = 0.64$ KSF

SPILLWAY STABILITY (CONT)

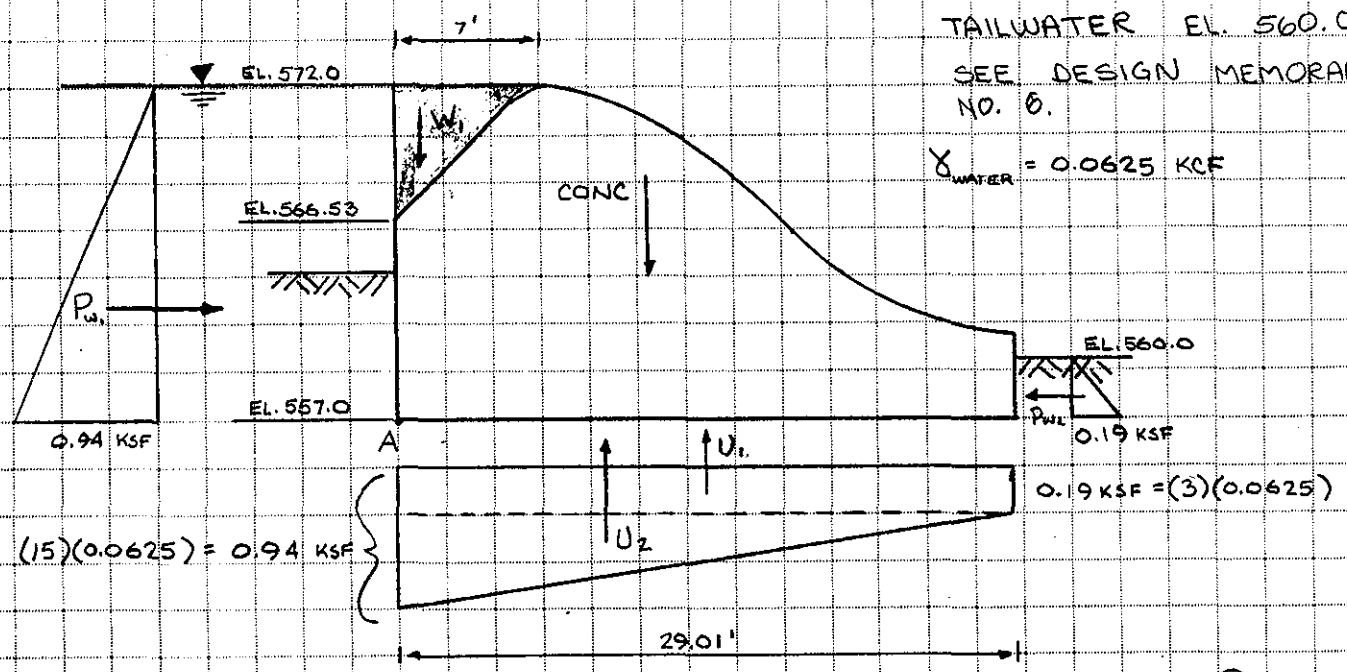
SECTION ③

LOADING CONDITION CASE II - NORMAL OPERATING CONDITIONS

CHECK OVERTURNING - REF. EM 1110-2-2200, CHAP 3-03

TAILWATER EL. 560.00
SEE DESIGN MEMORANDUM NO. 6.

$\gamma_{WATER} = 0.0625$ KCF



ITEM	FORCE (K/FT)	ARM (FT)	MOMENT (FT-K/FT) ↻ ABOUT A
CONC	44.23 ↓		522.11
W_1	$\frac{1}{2}(7.00)(5.47)(0.0625) = 1.20$ ↓	$\frac{1}{3}(7) = 2.33$	2.80
U_1	$(0.19)(29.01) = 5.51$ ↑	$\frac{1}{2}(29.01) = 14.51$	-79.95
U_2	$(0.94 - 0.19)(29.01)/2 = 10.88$ ↑	$\frac{1}{3}(29.01) = 9.67$	-105.21
P_{w_1}	$\frac{1}{2}(0.94)(15) = 7.05$ →	$\frac{1}{3}(15) = 5.00$	35.25
P_{w_2}	$\frac{1}{2}(0.19)(3) = 0.29$ ←	$\frac{1}{3}(3) = 1.00$	-0.29
	$\Sigma V = 29.04$ K/FT, $\Sigma H = 6.76$ K/FT		374.71 FT-K/FT

PRODUCT 204-1 NEBS Inc., Groton, Mass. 01471.

SPILLWAY STABILITY (CONT.)

SECTION ③

LOADING CONDITION CASE II (CONT.)

CHECK OVERTURNING (CONT.)

$$\Sigma M / \Sigma V = 374.71 / 29.04 = 12.90'$$

$9.67' < 12.90' < 19.34'$ OK

RESULTANT WITHIN MIDDLE THIRD OF BASE

(EM 1110-2-2200, PG. 8)

CHECK SLIDING - REF. ETL 1110-2-256

$$FS = \frac{(80\ PSI)(29.01\ FT)(144\ IN^2/FT^2) + (29040\ \#/FT)\ TAN\ 26.56^\circ}{6760\ \#/FT}$$

$FS = 51.59$

$51.59 > 2$ OK

(ETL 1110-2-256, PG. 20)

CHECK BEARING PRESSURE

$$f = \frac{29.04\ K/FT}{29.01\ FT} \pm \frac{(29.04\ K/FT)(12.93' - 14.51')(14.51')}{\frac{1}{12}(29.01')^3}$$

$= 1.00\ KSF \pm 0.33\ KSF$

$f_{UPSTREAM} = 1.33\ KSF$

OK ($f_{ALLOW} = 40\ KSF$)

$f_{DOWNSTREAM} = 0.67\ KSF$

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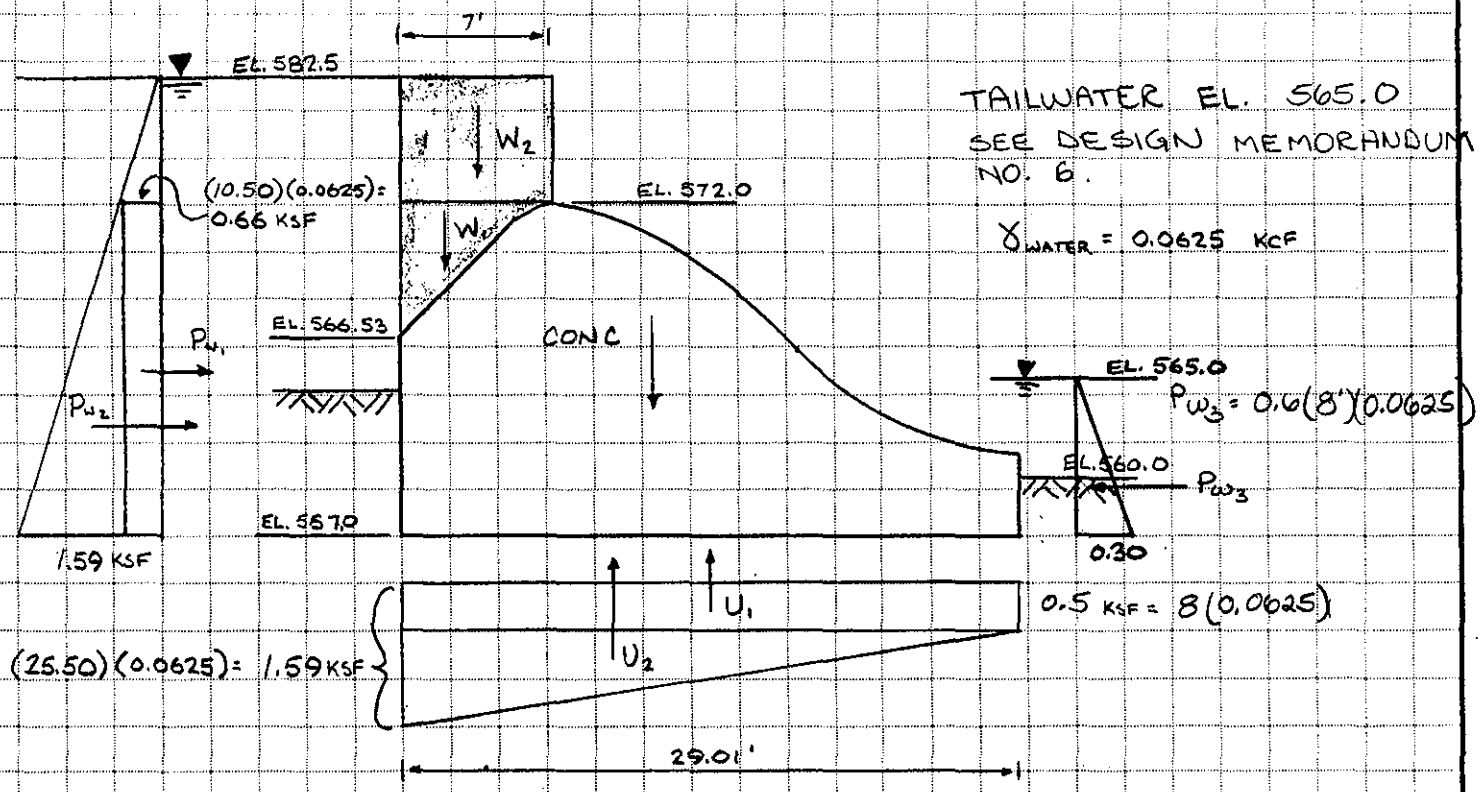
JOB WESTVILLE DAM STABILITY ANALYSIS
SHEET NO. 37 OF
CALCULATED BY JMS DATE 10/22/87
CHECKED BY LFV DATE 1/27/88
SCALE

SPILLWAY STABILITY (CONT)

SECTION ③

LOADING CONDITION CASE IV - FLOOD DISCHARGE CONDITION

CHECK OVERTURNING - REF. EM 1110-2-2200, CHAP 3-03



TAILWATER EL. 565.0
SEE DESIGN MEMORANDUM NO. 6.

γ_{WATER} = 0.0625 KCF

SPILLWAY STABILITY (CONT.)

SECTION ③

LOADING CONDITION CASE IV (CONT.)

CHECK OVERTURNING (CONT.)

ITEM	FORCE (K/FT)	ARM (FT)	MOMENT (FT·K/FT)
CONC.	44.23 ↓		522.11
W_1	1.20 ↓	2.33	2.80
W_2	(7)(10.50)(0.0625) = 4.59 ↓	$\frac{1}{2}(7) = 3.50$	16.07
U_1	(0.5)(29.01) = 14.51 ↑	$\frac{1}{2}(29.01) = 14.51$	-210.4
U_2	$\frac{1}{2}(1.59 - 0.5)(29.01) = 15.81$ ↑	$\frac{1}{3}(29.01) = 9.67$	-152.9
P_{w_1}	(0.66)(15) = 9.90 →	$\frac{1}{2}(15) = 7.50$	74.25
P_{w_2}	$\frac{1}{2}(1.59 - 0.66)(15) = 6.98$ →	$\frac{1}{3}(15) = 5.00$	34.90
P_{w_3}	$\frac{1}{2}(0.3)(8) = 1.20$ ←	$\frac{1}{3}(8) = 2.67$	-3.2
	$\Sigma V = 19.70$ K/FT, $\Sigma H = 15.68$ K/FT		283.63 FT·K/FT

$\Sigma M / \Sigma V = 283.63 / 19.70 = 14.4'$

$9.67' < 14.4' < 19.34'$ (OK)

RESULTANT WITHIN MIDDLE THIRD OF BASE

(EM 1110-2-2200, PG. 8)

SPILLWAY STABILITY (CONT.)

SECTION ③

LOADING CONDITION CASE IV (CONT.)

CHECK SLIDING - REF. ETL 1110-2-256

$$FS = \frac{(80\ PSL)(29.01\ FT)(144\ IN^2/FT^2) + (19{,}700\ \#/FT)\ TAN\ 26.56^\circ}{16160\ \#/FT}$$

$FS = 21.3$

$21.3 > 2$ OK

(ETL 1110-2-256, PG. 20)

CHECK BEARING PRESSURE

$$f = \frac{19.70\ K/FT}{29.01\ FT} \pm \frac{(19.70\ K/FT)(14.51' - 14.51')(14.51')}{\frac{1}{12}(29.01')^3}$$

$= 0.68\ KSF \pm 0.02\ KSF$

$f_{UPSTREAM} = 0.70\ KSF$

OK ($f_{ALLOW} = 40\ KSF$)

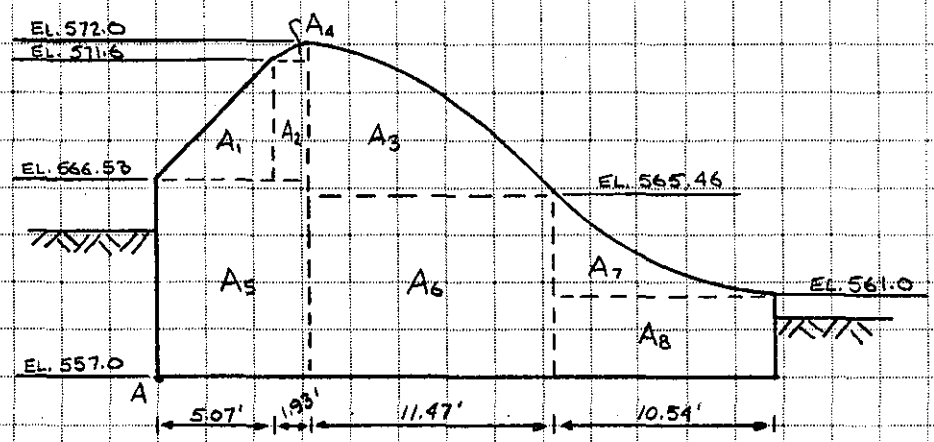
$f_{DOWNSTREAM} = 0.66\ KSF$

SPILLWAY STABILITY (CONT)

SECTION ③

LOADING CONDITION CASE V - CONSTRUCTION CONDITION WITH EARTHQUAKE - REF. EM 1110-2-2200, PG. 4b, 5

CHECK OVERTURNING - REF. EM 1110-2-2200, CHAP 3-03



SECTION	AREA (FT^2)	DISTANCE FROM BASE (Y) (FT)	AY (FT^3)
A_1	12.85	$9.53 + \frac{1}{3}(5.07) = 11.22$	144.18
A_2	9.79	$9.53 + \frac{1}{2}(5.07) = 12.07$	118.17
A_3	50.01	$8.46 + \frac{2}{5}(6.54) = 11.08$	554.11
A_4	0.61	$14.60 + \frac{4(0.40)}{3\pi} = 14.75$	9.00
A_5	66.71	$\frac{1}{2}(9.53) = 4.77$	318.21
A_6	97.04	$\frac{1}{2}(8.46) = 4.23$	410.48
A_7	15.67	$4 + \frac{1}{4}(4.46) = 5.12$	80.15
A_8	42.16	$\frac{1}{2}(4.00) = 2.00$	84.32
	294.84 FT^2		1718.62 FT^3

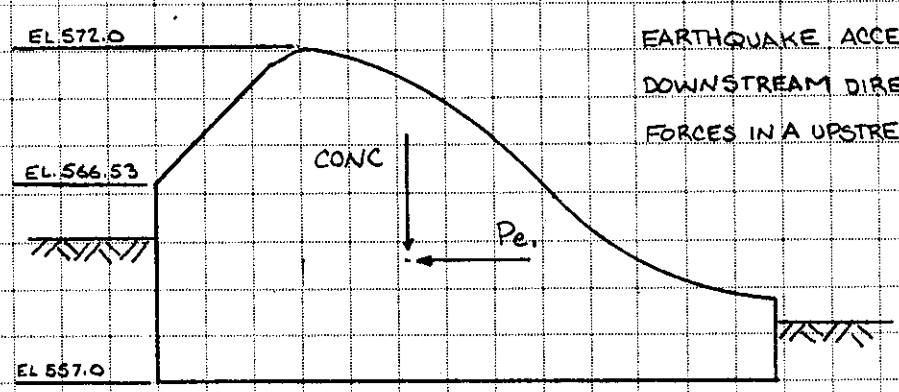
SPILLWAY STABILITY (CONT)

SECTION ③

LOADING CONDITION CASE V (CONT)

CHECK OVERTURNING (CONT)

$\Sigma AY / \Sigma A = 1718.62 / 294.84 = 5.83'$



EARTHQUAKE ACCELERATION IN A DOWNSTREAM DIRECTION. INERTIA FORCES IN A UPSTREAM DIRECTION.

EARTHQUAKE FORCE REQUIRED TO ACCELERATE SECTION

$P_e = \alpha W$ $\alpha = 0.10$ (ER 1110-2-1806, PG. 2)

$P_e = 0.10 (44.23) = 4.42$ K/FT

ITEM	FORCE (K/FT)	ARM (FT)	↻ ABOUT A MOMENT (FT-K/FT)
CONC	44.23 ↓		522.11
P_e,	4.42 ←	5.83	-25.77
	$\Sigma V = 44.23$ K/FT, $\Sigma H = 4.42$ K/FT		496.34 FT-K/FT

$\Sigma M / \Sigma V = 496.34 / 44.23 = 11.22'$

$9.67' < 11.22' < 19.34'$ (OK)

RESULTANT WITHIN MIDDLE THIRD OF BASE

(EM 1110-2-2200, PG. 8)

SPILLWAY STABILITY (CONT)

SECTION 3

LOADING CONDITION CASE V (CONT.)

CHECK SLIDING - REF ETL 1110-2-256

$$FS = \frac{(80\ PSI)(29.01\ FT)(144\ IN^2/FT^2) + (44230\ \#/FT)(TAN\ 26.56°)}{4420\ \#/FT}$$

$FS = 80.61$

$80.61 >> 1.3$ OK
(ETL 1110-2-256, PG. 20)

CHECK BEARING PRESSURE

$$f = \frac{44.23\ K/FT}{29.01\ FT} \pm \frac{(44.23\ K/FT)(11.22' - 14.51')(14.51')}{\frac{1}{12}(29.01')^3}$$

$= 1.52\ KSF \pm 1.04\ KSF$

$f_{UPSTREAM} = 2.56\ KSF$

OK ($f_{ALLOW} = 40\ KSF$)

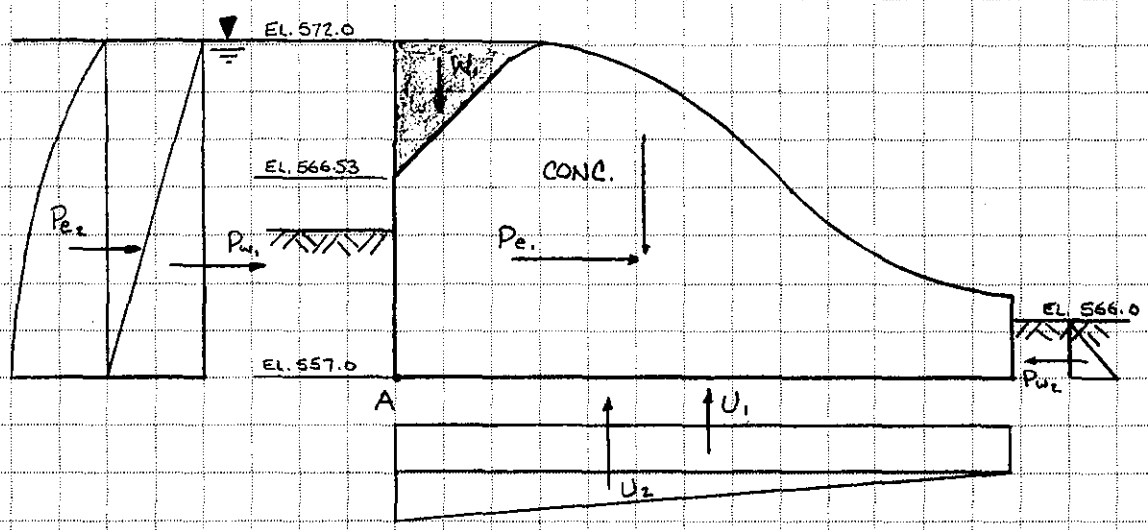
$f_{DOWNSTREAM} = 0.48\ KSF$

SPILLWAY STABILITY (CONT)

SECTION ③

LOADING CONDITION CASE VI - NORMAL OPERATING CONDITION WITH EARTHQUAKE

CHECK OVERTURNING - REF. EM 1110-2-2200, CHAP 3-03



SEE CASES II & V FOR CALCULATION OF FORCES AND MOMENT ARMS

EARTHQUAKE INERTIA OF RESERVIOR WATER (EM 1110-2-2200, PG. 4b, 5)

$$P_{e_2} = \frac{2}{3} C_e \alpha \gamma \sqrt{h\gamma}$$

$\alpha = 0.10$ (ER 1110-2-1806, PG 2)

$$C_e = \frac{51}{\sqrt{1 - 0.72\left(\frac{15}{1000}\right)^2}} = 51.00$$

$$P_{e_2} = \frac{2}{3}(51.00)(0.10)(15)(15)$$

$= 765$ lb ACTING @ $0.4(h) = 6.00'$ FROM BASE

SPILLWAY STABILITY (CONT.)

SECTION ③

LOADING CONDITION CASE VI (CONT.)

CHECK OVERTURNING (CONT.)

ITEM	FORCE (K/FT)	ARM (FT)	↻+ ABOUT A MOMENT (FT-K/FT)
CONC	44.23 ↓		522.11
W_1	1.20 ↓	2.33	2.80
U_1	5.51 ↑	14.51	-79.95
U_2	10.88 ↑	9.67	-105.21
P_{e_1}	4.42 →	5.83	25.77
P_{e_2}	0.77 →	6.00	4.62
P_{w_1}	7.05 →	5.00	35.25
P_{w_2}	0.29 ←	1.00	-0.29
	$\Sigma V = 29.04$ K/FT, $\Sigma H = 11.95$ K/FT		405.10 FT-K/FT

$$\Sigma M / \Sigma V = 405.10 / 29.04 = 13.95'$$

$9.67' < 13.95' < 19.34'$ (OK)

RESULTANT WITHIN MIDDLE THIRD OF BASE

(EM 1110-2-2200, PG. 8)

SPILLWAY STABILITY (CONT)

SECTION ③

LOADING CONDITION CASE VI (CONT.)

CHECK SLIDING - REF. ETL 1110-2-256

$$FS = \frac{(80\ PSL)(29.01\ FT)(144\ IN^2/FT^2) + (29040\ \#/FT)(TAN\ 26.56^\circ)}{11950\ \#/FT}$$

$FS = 29.18$

CHECK BEARING PRESSURE

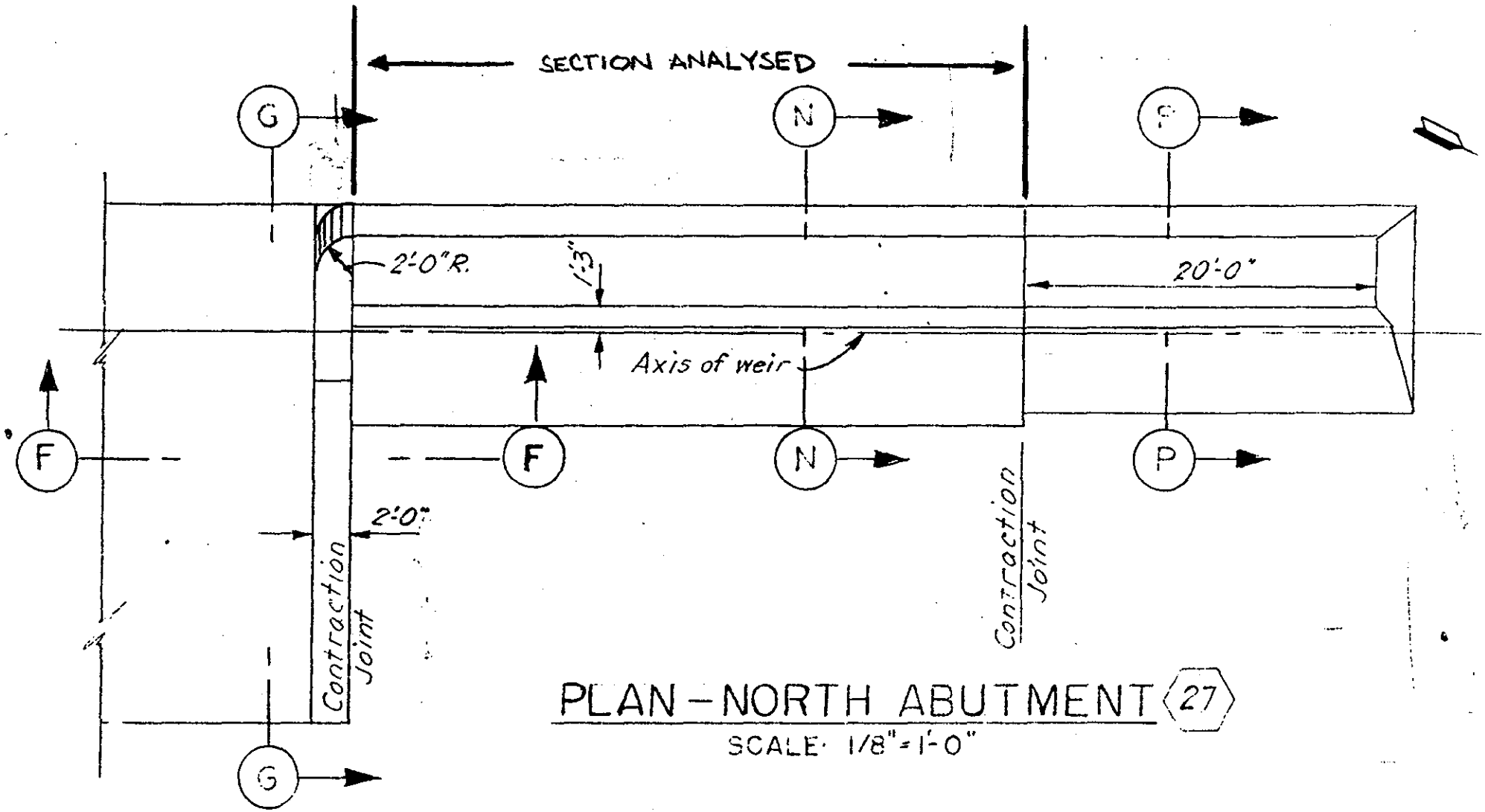
$$f = \frac{29.04\ K/FT}{29.01\ FT} \pm \frac{(29.04\ K/FT)(13.95 - 14.51)(14.51)}{\frac{1}{12}(29.01)^3}$$

$= 1.00\ KSF \pm 0.11\ KSF$

$F_{UPSTREAM} = 1.11\ KSF$

OK ($F_{ALLOW} = 40\ KSF$)

$F_{DOWNSTREAM} = 0.89\ KSF$



PLAN – NORTH ABUTMENT (27)

SCALE: 1/8" = 1'-0"

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JOB WESTVILLE DAM STABILITY ANALYSIS
SHEET NO. 47 OF
CALCULATED BY JMS DATE 10/27/87
CHECKED BY LFV DATE 1/27/88
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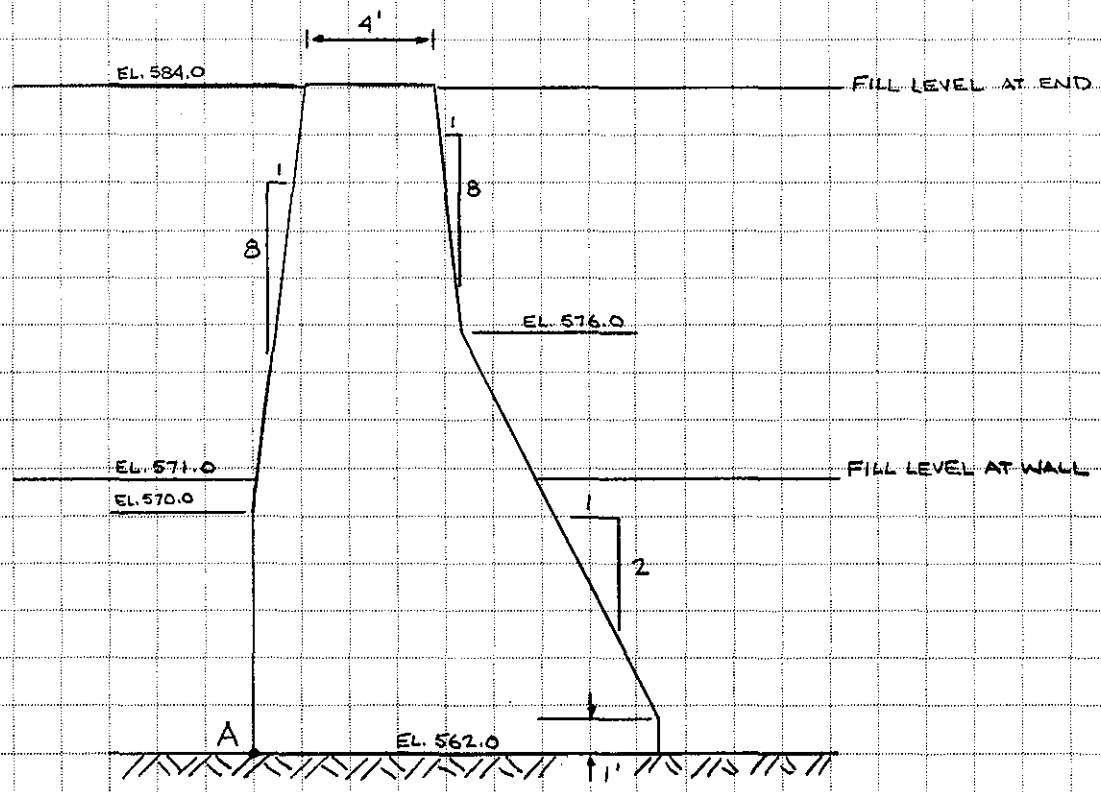
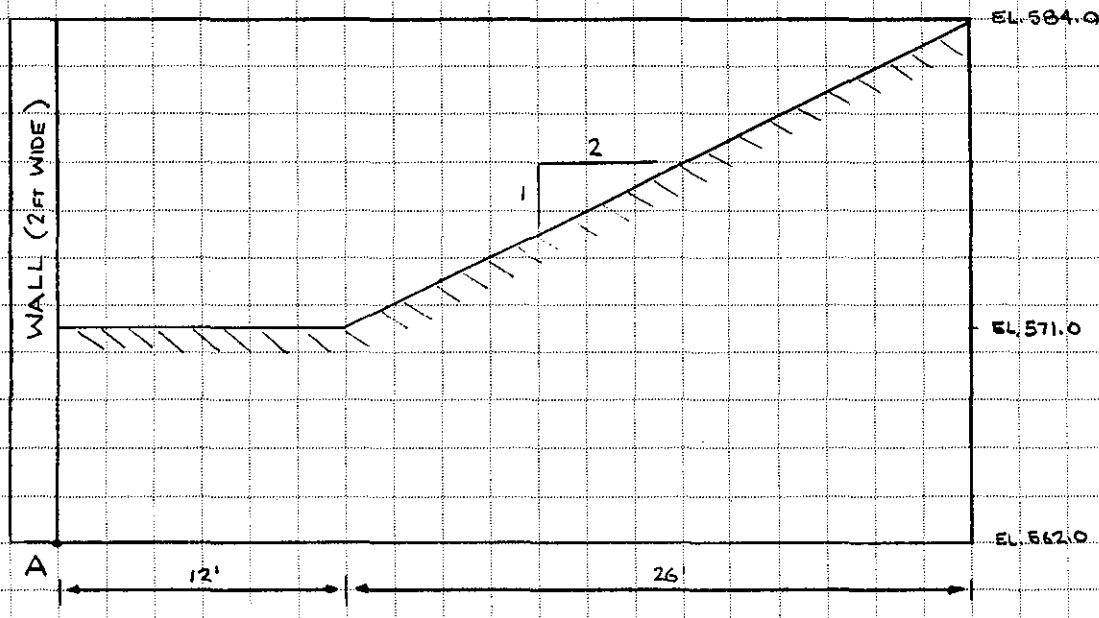
NORTH ABUTMENT STABILITY

SECTION



SIDE ELEVATION



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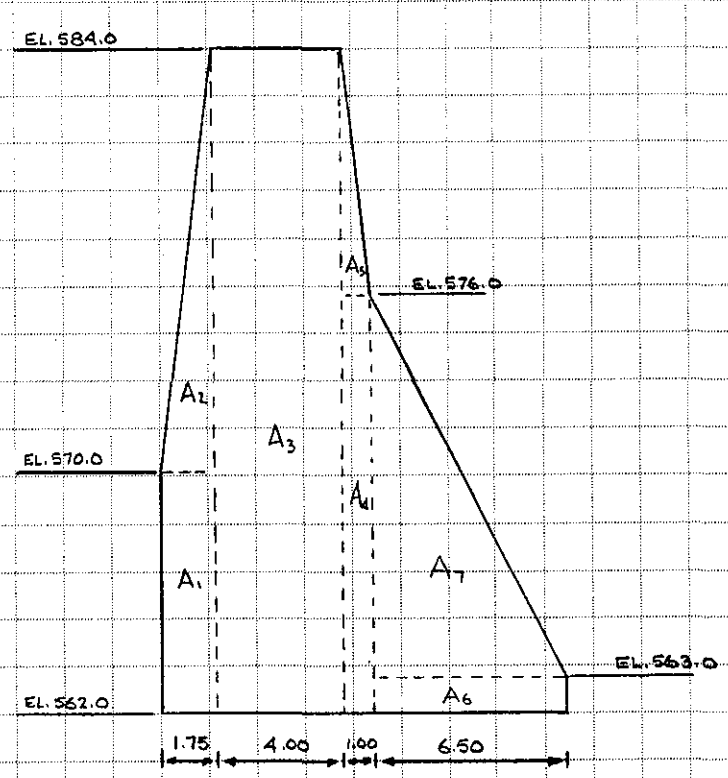
JOB: WESTVILLE DAM STABILITY ANALYSIS
SHEET NO. 48 OF
CALCULATED BY: JMS DATE: 10/27/87
CHECKED BY: LFV DATE: 1/27/88
SCALE

NORTH ABUTMENT STABILITY (CONT)

SECTION



SECTION	AREA	WEIGHT	VERT ARM	@A MOMENT	HORIZ ARM	@A MOMENT
A_1	(1.75)(8) = 14.00	2.10	4.00	8.40	0.88	1.84
A_2	½(1.75)(14) = 12.25	1.84	12.67	23.27	1.17	2.14
A_3	4(22) = 88.00	13.20	11.00	145.20	3.75	49.50
A_4	(1)(14) = 14.00	2.10	7.00	14.70	6.25	13.13
A_5	½(1)(8) = 4.00	0.60	16.67	10.00	6.08	3.65
A_6	(6.5)(.1) = 6.50	0.98	0.50	0.49	10.00	9.75
A_7	½(6.5)(13) = 42.25	6.34	5.33	33.80	8.92	56.51
		27.150	8.687	235.863	5.03	136.52

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NORTH ABUTMENT STABILITY (CONT)

CONCRETE SECTION

WEIGHT OF WALL = 27.15 K/FT × 38 FT
= 1031.70 K

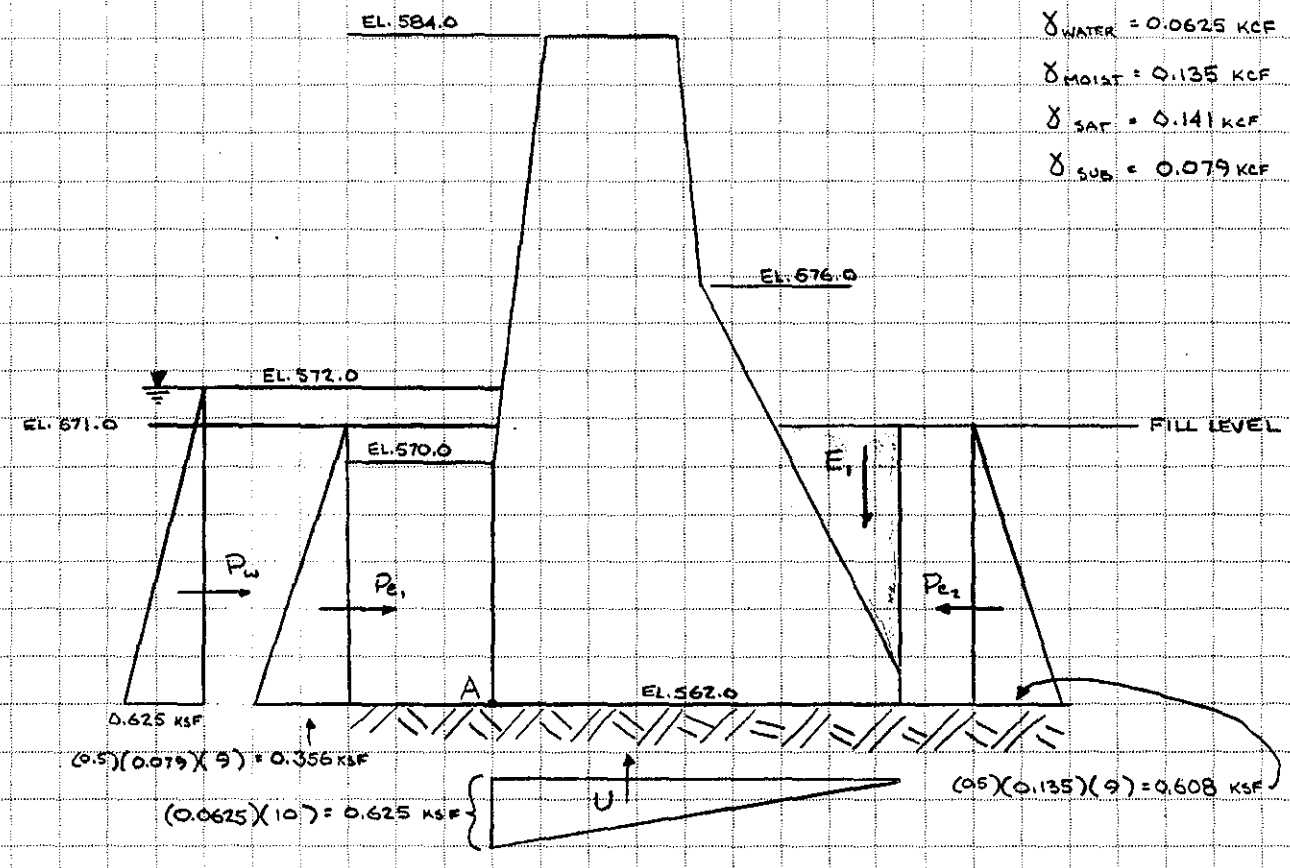
MOMENT ABOUT A = 1031.70 K × 5.03
ALONG X-X AXIS
= 5189.45 FT-K

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE I - USUAL FLOOD LOADING

SECTION FROM WALL TO 12 FT

FORCES ACTING ON SECTION



ITEM	FORCE	ARM	MOMENT
E_1	$\frac{1}{2}(4)(8)(0.135) = 2.160 \downarrow$	11.917	25.740
U_1	$\frac{1}{2}(0.625)(13.25) = 4.141 \uparrow$	4.417	-18.289
P_{e_1}	$\frac{1}{2}(0.356)(9) = 1.602 \rightarrow$	3.000	4.806
P_{e_2}	$\frac{1}{2}(0.608)(9) = 2.736 \leftarrow$	3.000	- 8.208
P_w	$\frac{1}{2}(0.625)(10) = 3.125 \rightarrow$	3.333	10.417
	$\Sigma V = -1.981$ K/FT $\Sigma H = 1.991$ K/FT		$\Sigma M = 14.466$ FT-K/FT

$V = -1.981$ K/FT $\times$ 12 FT $= -23.772$ K $\qquad M = 14.466$ FT-K/FT $\times$ 12 FT $= 173.592$ FT-K

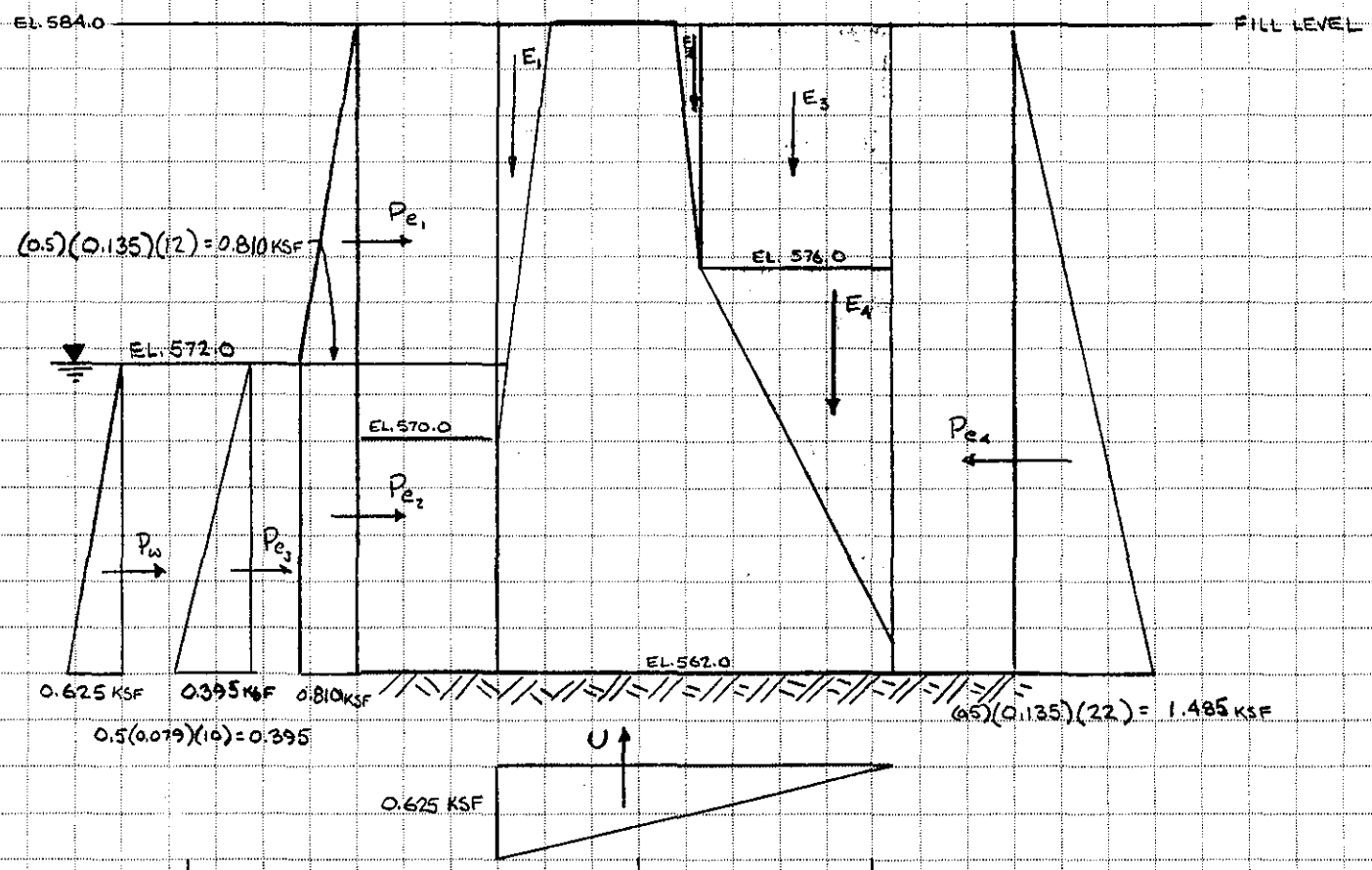
$H = 1.991$ K/FT $\times$ 12 FT $= 23.892$ K

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE I (CONT)

SECTION AT END

FORCES ACTING ON SECTION



ITEM	FORCE	ARM	MOMENT
E_1	$\frac{1}{2}(0.135)(1.75)(14) = 1.654$ ↓	0.583	0.965
E_2	$\frac{1}{2}(0.135)(1)(8) = 0.540$ ↓	6.417	3.465
E_3	$(0.135)(8)(6.5) = 7.020$ ↓	10.000	70.200
E_4	$\frac{1}{2}(0.135)(6.5)(13) = 5.704$ ↓	11.083	63.219
U_1	4.141 ↑	4.417	-18.289
P_{e_1}	$\frac{1}{2}(0.810)(12) = 4.860$ →	14.000	68.040
P_{e_2}	$(0.810)(10) = 8.100$ →	5.000	40.500
P_{e_3}	$\frac{1}{2}(0.395)(10) = 1.975$ →	3.333	6.583
P_{e_4}	$\frac{1}{2}(1.485)(22) = 16.335$ ←	7.333	-119.790
P_w	$\frac{1}{2}(0.625)(10) = 3.125$ →	3.333	10.417
	$\Sigma V = 10.777^{K}/_{FT}$ $\Sigma H = -1.725^{K}/_{FT}$		$\Sigma M = 125.310^{T\cdot K}/_{FT}$

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE I (CONT)

SECTION FROM 12FT TO END

$$V = \left(\frac{-1.981\ ^{K}/_{FT} + 10.777\ ^{K}/_{FT}}{2}\right) 26 = 114.348^{K}$$

$$H = \left(\frac{-1.991\ ^{K}/_{FT} + 1.725\ ^{K}/_{FT}}{2}\right) 26 = 48.308^{K}$$

$$M = \left(\frac{14.466\ ^{FT\text{-}K}/_{FT} + 125.31\ ^{FT\text{-}K}/_{FT}}{2}\right) 26 = 1817.088^{FT\text{-}K}$$

TOTAL LENGTH

$$V = \underset{(WALL)}{1031.700} - \underset{(12FT\ SECTION)}{23.772} + \underset{(12FT\ TO\ END)}{114.348}$$

$$V_T = 1122.28^{K}$$

$$H = \underset{(12FT\ SECTION)}{23.892} + \underset{(12FT\ TO\ END)}{48.308}$$

$$H_T = 72.20^{K}$$

ABOUT A

$$M = \underset{(WALL)}{5189.45} + \underset{(12FT\ SECTION)}{173.59} + \underset{(12FT\ TO\ END)}{1817.09}$$

$$M_T = 7180.13^{FT\text{-}K}$$

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE I (CONT)

CHECK OVERTURNING - REF. EM 1110-2-2501, PG. 17

$\Sigma M / \Sigma V = 7180.13 / 1122.28 = 6.40'$

$4.42' < 6.40' < 8.83'$ OK RESULTANT WITHIN MIDDLE 1/3 (EM 1110-2-2502)

CHECK SLIDING - REF. ETL 1110-2-256

$$FS = \frac{(80\,PSI)(13.25\,FT)(38\,FT)(144\,IN^2/FT^2) + (1122280^{\#})\,TAN\,26.56^\circ}{72200^{\#}}$$

$FS = 88 >> 2$ OK (ETL 1110-2-256, PG. 20)

CHECK BEARING PRESSURE

$$F = \frac{1122.28^K}{(13.25')(38')} \pm \frac{(1122.28^K)(6.40' - 6.63')(6.63')}{\frac{1}{12}(38')(13.25')^3}$$

$= 2.23\,KSF \pm 0.24\,KSF$

$F_{UPSTREAM} = 2.47\,KSF$

OK ($F_{ALLOW} = 40\,KSF$)

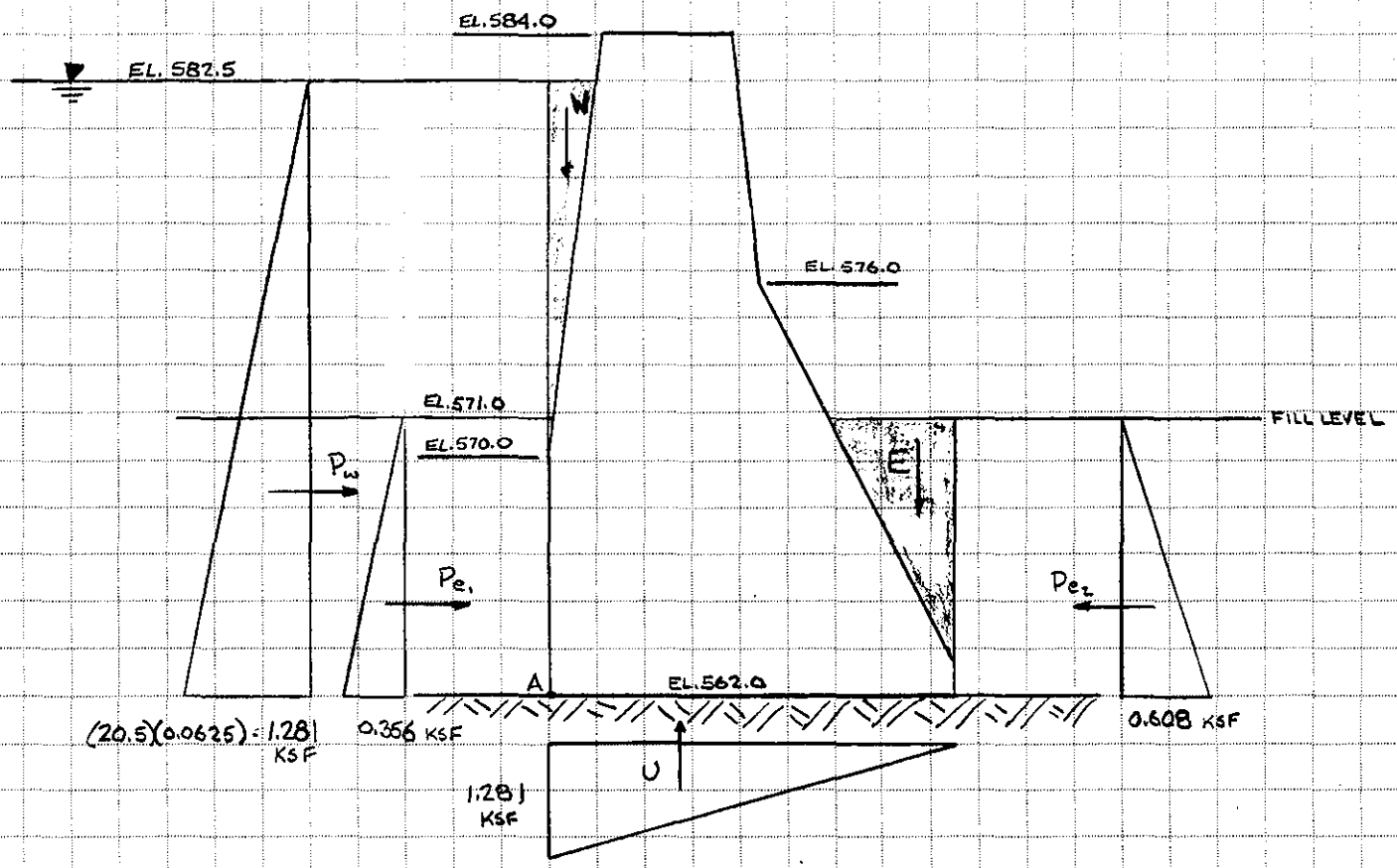
$F_{DOWNSTREAM} = 1.98\,KSF$

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE II - EXTREME FLOOD LOADING

SECTION FROM WALL TO 12 FT

FORCES ACTING ON SECTION



ITEM	FORCE	ARM	MOMENT
E	2.160 ↓	11.917	25.740
W	$\frac{1}{2}(1.56)(12.5)(0.0625) = 0.610$ ↓	0.521	0.318
U	$\frac{1}{2}(1.281)(13.25) = 8.487$ ↑	4.417	-37.487
P_{e_1}	$\frac{1}{2}(0.356)(9) = 1.602$ →	3.000	4.806
P_{e_2}	$\frac{1}{2}(0.608)(9) = 2.734$ ←	3.000	-8.202
P_w	$\frac{1}{2}(1.281)(20.5) = 13.130$ →	6.833	89.717
	$\Sigma V = -5.717$ K/FT, $\Sigma H = 11.998$ K/FT		$\Sigma M = 74.892$ FT-K/FT

$V = -5.717$ K/FT $\times$ 12 FT $= -68.604$ K

$M = 74.892$ FT-K/FT $\times$ 12 FT $= 898.704$ FT-K

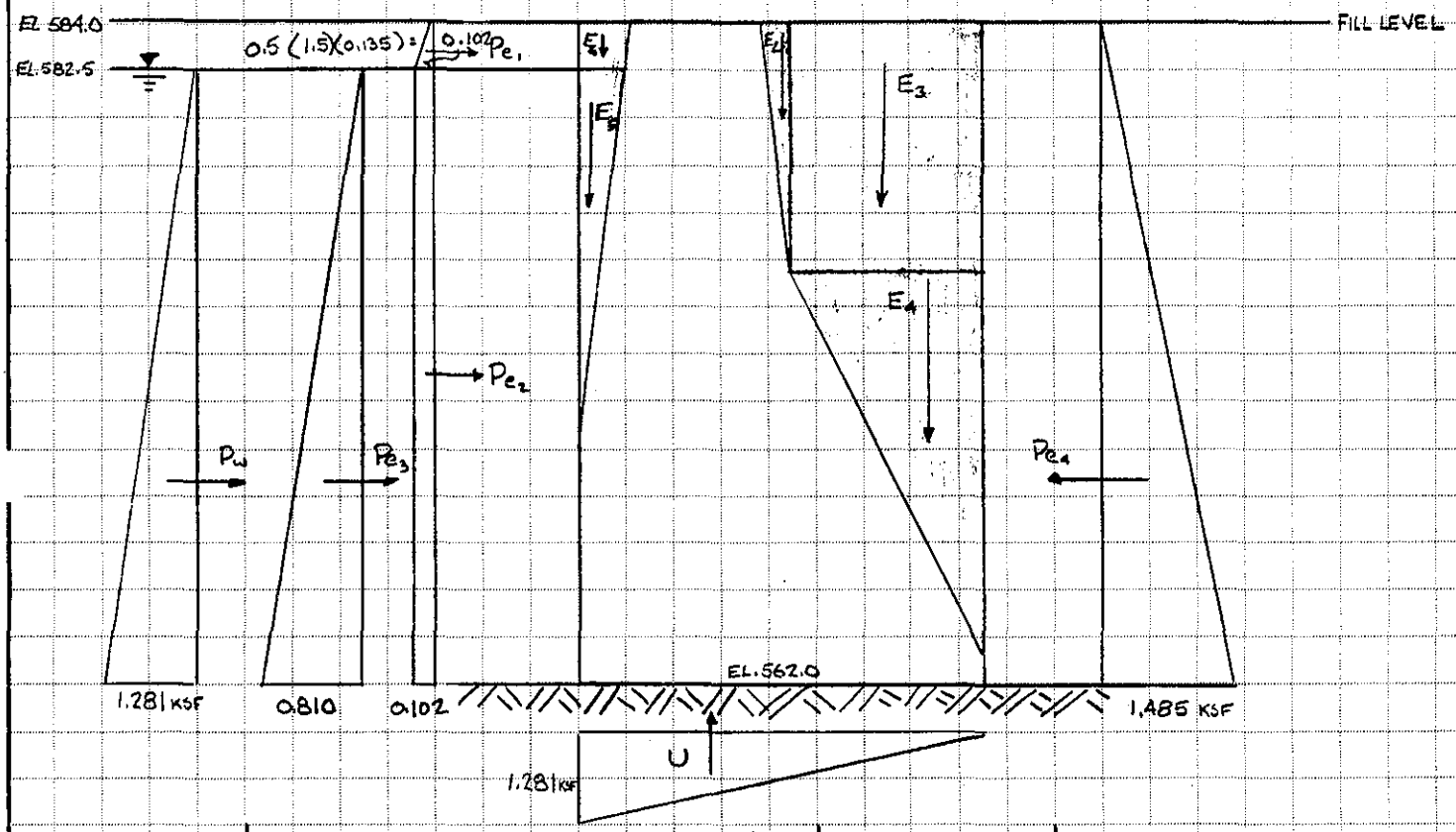
$H = 11.998$ K/FT $\times$ 12 FT $= 143.976$ K

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE II (CONT.)

SECTION AT END

FORCES ACTING ON SECTION



ITEM	FORCE	ARM	MOMENT
E_2	0.540 ↓	6.417	3.465
E_3	7.020 ↓	10.000	70.200
E_4	5.704 ↓	11.083	63.217
E_5	$\frac{1}{2}(0.141)(1.56)(12.5) = 1.377$ ↓	0.521	0.717
E_6	$(0.135)(1.5)(\frac{1.56+1.75}{2}) = 0.335$ ↓	0.828	0.277
U	8.487 ↑	4.417	-37.487
P_{e_1}	$\frac{1}{2}(0.102)(1.5) = 0.076$ →	21.000	1.596
P_{e_2}	$(0.102)(20.5) = 2.081$ →	10.250	21.331
P_{e_3}	$\frac{1}{2}(0.810)(20.5) = 8.303$ →	6.833	56.734
P_{e_4}	16.335 ←	7.333	-119.785
P_w	13.130 →	6.833	89.717
	$\Sigma V = 6.489$ K/FT, $\Sigma H = 7.255$ K/FT		$\Sigma M = 149.982$ FT-K/FT

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE II (CONT)

SECTION FROM 12FT TO END

$$V = \left(\frac{-5.717 + 6.489}{2}\right) 26 = 10.036^{K}$$

$$H = \left(\frac{11.998 + 7.225}{2}\right) 26 = 249.899^{K}$$

$$M = \left(\frac{74.892 + 149.982}{2}\right) 26 = 2923.36^{FT\text{-}K}$$

TOTAL LENGTH

$$V = \underset{(WALL)}{1031.700} - \underset{(12FT\ SECTION)}{68.604} + \underset{(12FT\ TO\ END)}{10.036}$$

$$V_T = 973.13^{K}$$

$$H = \underset{(12FT\ SECTION)}{143.976} + \underset{(12FT\ TO\ END)}{249.899}$$

$$H_T = 393.88^{K}$$

$$M^{ABOUT\ A} = \underset{(WALL)}{5189.45} + \underset{(12\ FT\ SECTION)}{898.704} + \underset{(12FT\ TO\ END)}{2923.36}$$

$$M_T = 9011.5^{FT\text{-}K}$$

NORTH ABUTMENT STABILITY (CONT.)

LOADING CONDITION CASE II (CONT.)

CHECK OVERTURNING - REF. EM 1110-2-2501, PG. 17

$\Sigma M / \Sigma V = 9011.5 / 973.13 = 9.26'$

RESULTANT WITHIN THE BASE

$0 < 9.26 < 13.25$ OK

IF ALL OTHER CONDITIONS ARE SATISFIED (EM 1110-2-2502)

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE II (CONT)

CHECK SLIDING - REF. ETL 1110-2-256

$$FS = \frac{(80\ PSL)(13.25\ FT)(38\ FT)(144\ IN^2/FT^2) + (973130\ \#)\tan 26.56^\circ}{393880\ \#}$$

$FS = 16 > 2$ OK (ETL 1110-2-256, PG. 20)

CHECK BEARING PRESSURE

$$f_{max} = \frac{2V}{3e} \qquad e = 13.25 - 9.26 = 3.99' \qquad V = \frac{973.13^K}{38'} = 25.6\ ^K/_{FT}$$

$$= \frac{2(25.6)}{3(3.99)}$$

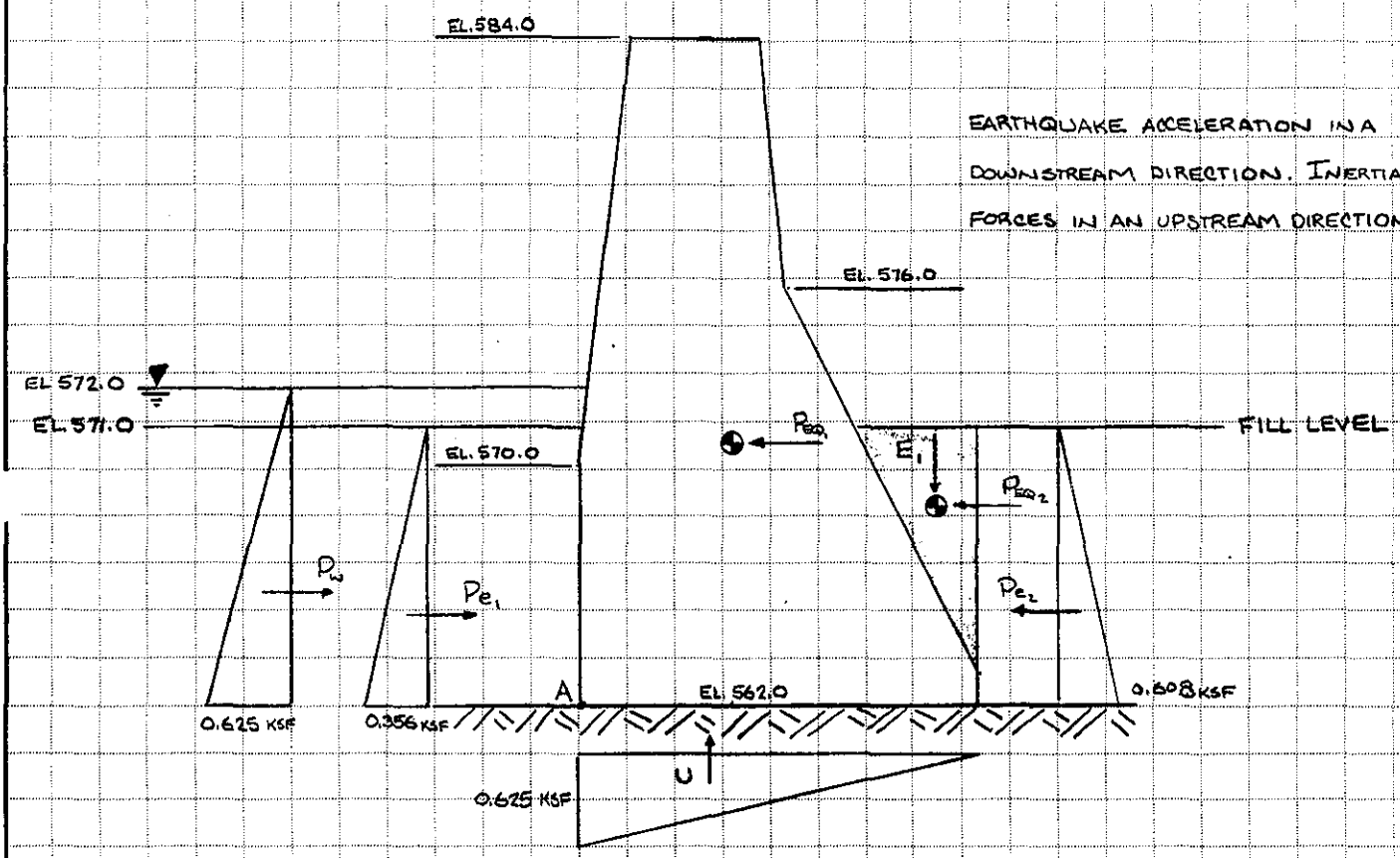
$= 4.28$ KSF OK ($F_{ALLOW} = 40$ KSF)

NORTH ABUTMENT STABILITY (CONT.)

LOADING CONDITION CASE III - EARTHQUAKE LOADING DOWNSTREAM

SECTION FROM WALL TO 12 FT

FORCES ACTING ON SECTION



EARTHQUAKE FORCE REQUIRED TO ACCELERATE SECTION

$P_{EQ} = \alpha W$ $\alpha = 0.10$ (ER 1110-2-1806, PG. 2)

$P_{EQ_1} = 0.10(27.150) = 2.715$ K/FT

$P_{EQ_2} = 0.10(2.160) = 0.216$ K/FT

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE III a (CONT)

SECTION FROM WALL TO 12 FT (CONT)

ITEM	FORCE	ARM	MOMENT
E_1	2.160 ↓	11.917	25.741
U	4.141 ↑	4.417	-18.291
P_{e_1}	1.602 →	3.000	4.806
P_{e_2}	2.736 ←	3.000	-8.208
P_w	3.125 →	3.333	10.416
P_{EQ_1}	2.715 ←	8.687	-23.585
P_{EQ_2}	0.216 ←	6.333	-1.368
	$\Sigma V = -1.981$ K/FT		$\Sigma M = -10.489$ FT-K/FT

$\Sigma H = -0.940$ K/FT

$V = -1.981$ K/FT $\times$ 12 FT $= -23.772$ K $\quad M = -10.489$ FT-K/FT $\times$ 12 FT $= -125.87$ FT-K

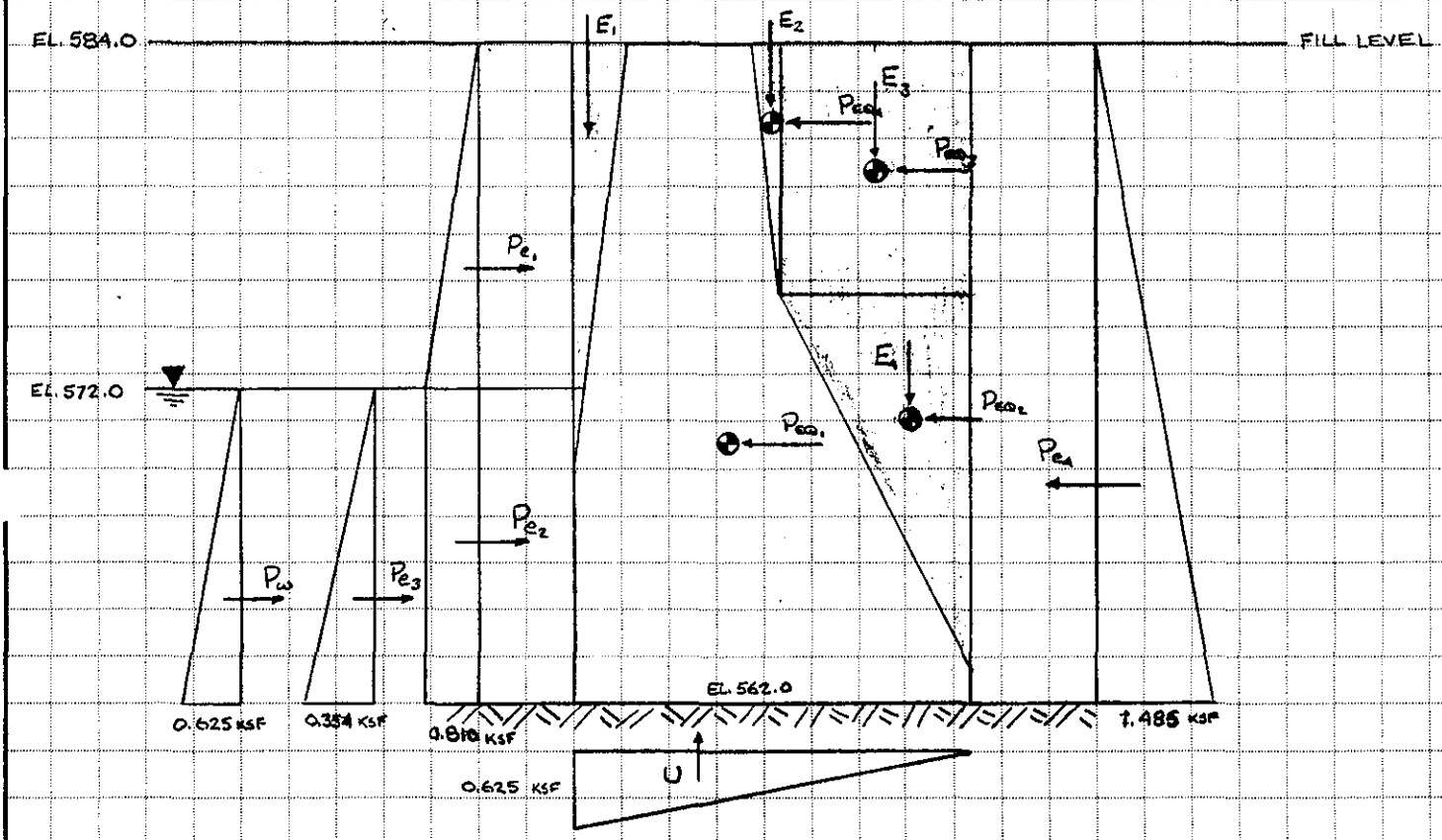
$H = -0.940$ K/FT $\times$ 12 FT $= -11.280$ K

NORTH ABUTMENT STABILITY (CONT.)

LOADING CONDITION CASE III a (CONT)

SECTION AT END

FORCES ACTING ON SECTION



EARTHQUAKE FORCE REQUIRED TO ACCELERATE SECTION

$P_{EQ} = \alpha W$

$P_{EQ_1} = 2.715$ K/FT

$P_{EQ_2} = 0.10(5.704) = 0.570$ K/FT

$P_{EQ_3} = 0.10(7.020) = 0.702$ K/FT

$P_{EQ_4} = 0.10(0.540) = 0.054$ K/FT

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE III a (CONT)

SECTION AT END (CONT)

ITEM	FORCE	ARM	MOMENT
E_1	1.654 ↓	0.583	0.965
E_2	0.540 ↓	6.417	3.465
E_3	7.020 ↓	10.000	70.200
E_4	5.704 ↓	11.083	63.219
U	4.141 ↑	4.417	-18.289
P_{e_1}	4.860 →	14.000	68.040
P_{e_2}	8.100 →	5.000	40.500
P_{e_3}	1.770 →	3.333	5.900
P_{e_4}	16.335 ←	7.333	-119.790
P_w	3.125 →	3.333	10.417
P_{EQ_1}	2.715 ←	8.687	-23.585
P_{EQ_2}	0.570 ←	9.667	-5.510
P_{EQ_3}	0.702 ←	18.000	-12.636
P_{EQ_4}	0.054 ←	19.333	-1.044
	$\Sigma V = 10.777$ K/FT		$\Sigma M = 81.852$ FT-K/FT

$\Sigma H = -2.521$ K/FT

$$V = \frac{(-1.981 + 10.777)}{2} \times 26 = 114.348^{K}$$

$$H = \left(\frac{-0.940 - 2.521}{2}\right) \times 26 = -44.993^{K}$$

$$M = \left(\frac{-10.489 + 81.852}{2}\right) \times 26 = 927.719^{FT\text{-}K}$$

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE IIIa (CONT)

TOTAL LENGTH

$V = 1031.700 - 23.772 + 114.348$
(WALL) (12 FT SECTION) (12 FT TO END)

$V_T = 1122.28^K$

$H = -11.280 - 44.993$
(12 FT SECTION) (12 FT TO END)

$H_T = -56.273$

$M = 5189.45 - 125.87 + 927.719$
(WALL) (12 FT SECTION) (12 FT TO END)

$M_T = 5991.30^{FT-K}$

CHECK OVERTURNING - REF. EM 1110-2-2501, PG. 17

$\Sigma M / \Sigma V = \frac{5991.30}{1122.28} = 5.34'$

$4.42 < 5.34 < 8.83$ OK RESULTANT WITHIN MIDDLE 1/3 (EM 1110-2-2502)

CHECK SLIDING - REF ETL 1110-2-256

$$FS = \frac{(80\ PSI)(13.25\ FT)(38\ FT)(144\ IN^2/FT^2) + (1122280\ \#)\ TAN\ 26.56^\circ}{56273\ \#}$$

$FS = 1.13 > 1.3$ OK (ETL 1110-2-256, PG. 20)

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE IIIa (CONT)

CHECK BEARING PRESSURE

$$f = \frac{1122.28^K}{(13.25')(38')} \pm \frac{(1122.28^K)(5.34 - 6.63)(6.63)}{\frac{1}{12}(38')(13.25')^3}$$

$$= 2.23 \text{ KSF} \pm 1.30 \text{ KSF}$$

$f_{UPSTREAM} = 3.53$ KSF

OK ($F_{ALLOW} = 40$ KSF)

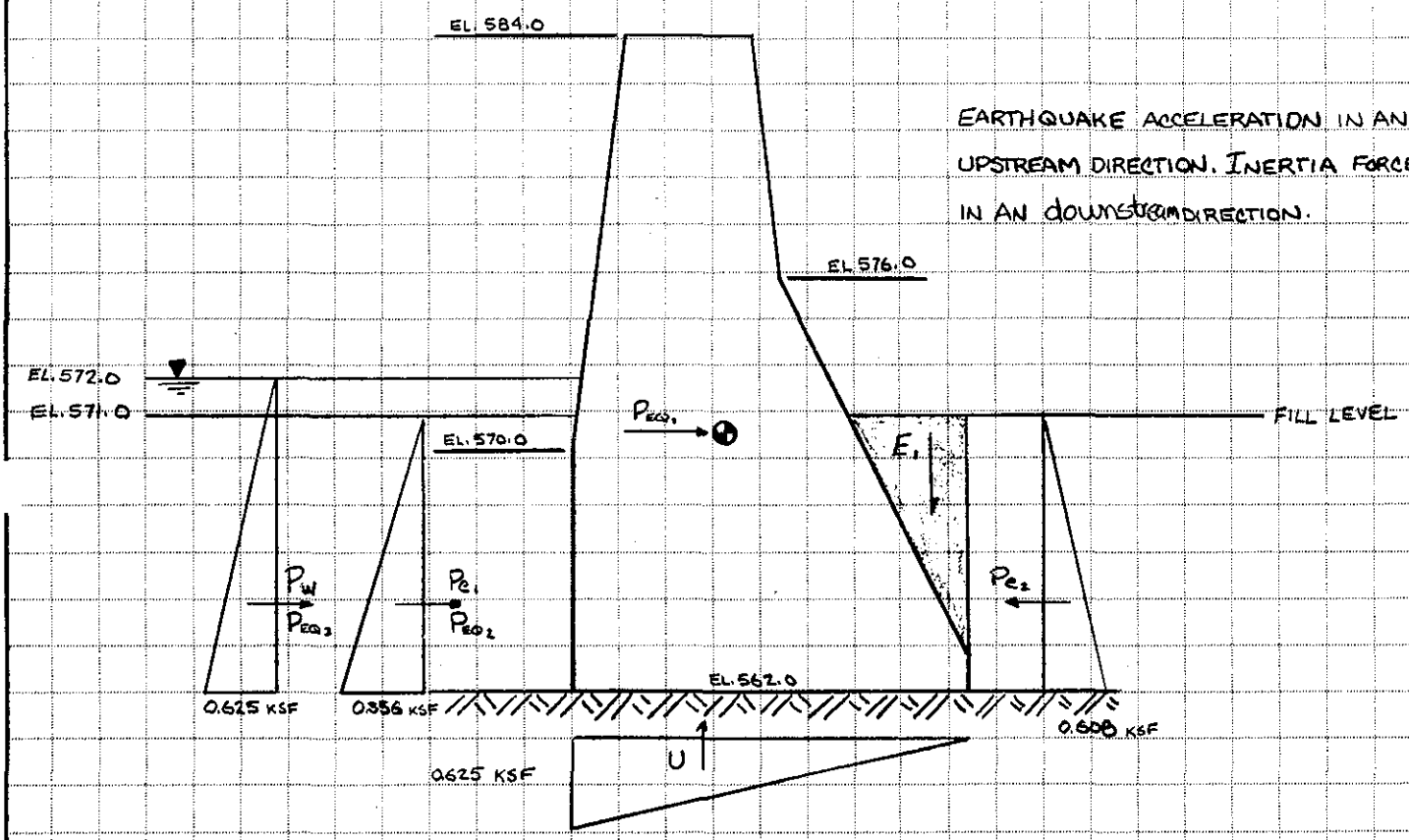
$f_{DOWNSTREAM} = 0.93$ KSF

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE III D - EARTHQUAKE LOADING UPSTREAM

SECTION FROM WALL TO 12 FT

FORCES ACTING ON SECTION



EARTHQUAKE FORCE REQUIRED TO ACCELERATE SECTION

$P_{EQ} = 2\alpha$ (STATIC PRESSURE) (EM 1110-2-2502, PG. 6)

$P_{EQ_2} = 2(0.10)(\frac{1}{2}(0.356)(9)) = 0.320$ K/FT

$P_{EQ_3} = 2(0.10)(\frac{1}{2}(0.625)(10)) = 0.625$ K/FT

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE III b (CONT)

SECTION FROM WALL TO 12 FT (CONT)

ITEM	FORCE	ARM	MOMENT
E_1	2.160 ↓	11.917	25.741
U	4.141 ↑	4.417	-18.291
P_{e_1}	7.602 →	3.000	4.806
P_{e_2}	2.736 ←	3.000	-8.208
P_w	3.125 →	3.333	10.416
P_{EQ_1}	2.715 →	8.687	23.585
P_{EQ_2}	0.320 →	3.000	0.960
P_{EQ_3}	0.625 →	3.333	2.083
	$\Sigma V = -1.981$ K/FT		$\Sigma M = 41.092$ FT-K/FT

$\Sigma H = 5.651$ K/FT

$V = -1.981 \text{ K/FT} \times 12 = -23.772 \text{ K}$ $M = 41.092 \text{ FT-K/FT} \times 12 = 493.104 \text{ FT-K}$

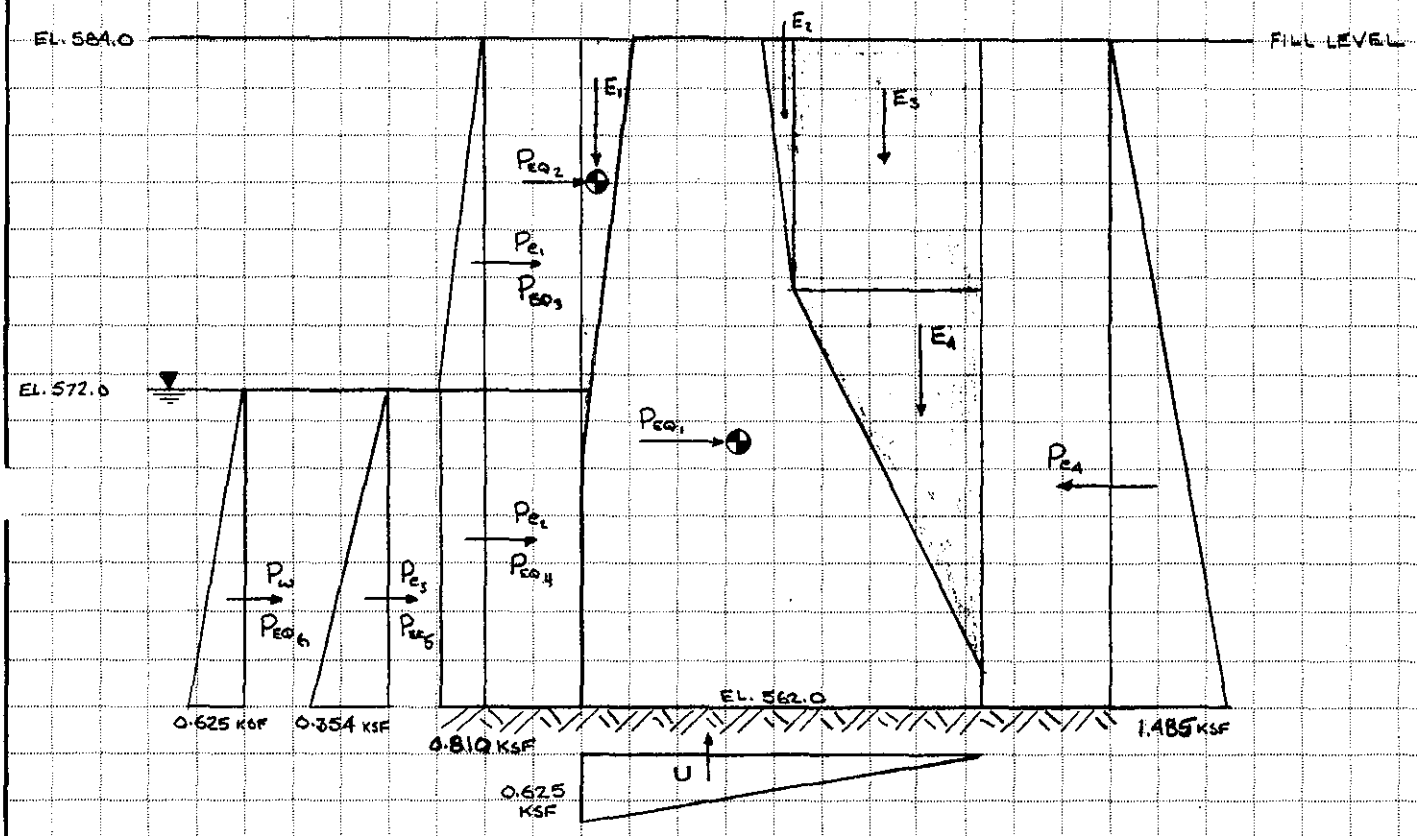
$H = 5.651 \text{ K/FT} \times 12 = 67.812 \text{ K}$

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE IIIb (CONT)

SECTION AT END

FORCES ACTING ON SECTION



EARTHQUAKE FORCE REQUIRED TO ACCELERATE SECTION

REF. EM 1110-2-2502, PG. 6

$P_{EQ} = \alpha W$ FOR SLOPED FACE

$P_{EQ_2} = 0.10(1.654) = 0.165$ K/FT

$P_{EQ} = 2\alpha$ (STATIC PRESSURE) FOR VERTICAL FACE

$P_{EQ_3} = 2(0.10)(\frac{1}{2}(12)(0.81)) = 0.972$ K/FT

$P_{EQ_4} = 2(0.10)(8.100) = 1.620$ K/FT

$P_{EQ_5} = 2(0.10)(1.770) = 0.354$ K/FT

$P_{EQ_6} = 2(0.10)(3.125) = 0.625$ K/FT

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE III D (CONT)

SECTION AT END (CONT)

ITEM	FORCE	ARM	MOMENT
E_1	1.654 ↓	0.583	0.965
E_2	0.540 ↓	6.417	3.465
E_3	7.020 ↓	10.000	70.200
E_4	5.704 ↓	11.083	63.219
U	4.141 ↑	4.417	-18.289
P_{e_1}	4.860 →	14.000	68.040
P_{e_2}	8.100 →	5.000	40.500
P_{e_3}	1.770 →	3.333	5.900
P_{e_4}	16.335 ←	7.333	-119.790
P_{w}	3.125 →	3.333	10.417
P_{EQ_1}	2.715 →	8.687	23.585
P_{EQ_2}	0.165 →	17.333	2.860
P_{EQ_3}	0.972 →	18.000	17.500
P_{EQ_4}	1.620 →	5.000	8.100
P_{EQ_5}	0.354 →	3.333	1.180
P_{EQ_6}	0.625 →	3.333	2.083
	$\Sigma V = 10.777$ K/FT		$\Sigma M = 179.94$ FT-K/FT

$\Sigma H = 7.971$ K/FT

$$V = \left(\frac{-1.981 + 10.777}{2}\right) \times 26 = 114.348^{K}$$

$$H = \left(\frac{6.651 + 7.971}{2}\right) \times 26 = 177.086^{K}$$

$$M = \left(\frac{41.092 + 179.94}{2}\right) \times 26 = 2873.42 \text{ FT-K}$$

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE IIIb (CONT)

TOTAL LENGTH

$V = 1031.700 - 23.772 + 114.348$
(WALL) (12FT SECTION) (12FT TO END)

$V_T = 1122.276^K$

$H = 67.812 + 177.086$
(12FT SECTION) (12FT TO END)

$H_T = 244.898^K$

$M = 5189.45 + 493.104 + 2873.42$
(WALL) (12FT SECTION) (12FT TO END)

$M_T = 8551.97$ FT-K

CHECK OVERTURNING - REF. EM 1110-2-2501, PG. 17

$\Sigma M / \Sigma V = 8551.97 / 1122.276 = 7.62'$

$4.42 < 7.62 < 8.83$ OK RESULTANT WITHIN MIDDLE 1/3
(EM 1110-2-2502)

CHECK SLIDING - REF. ETL 1110-2-256

$$FS = \frac{(80\,PSI)(13.25\,FT)(38\,FT)(144\,IN^2/FT^2) + (1122276\,\#)\ \tan 26.56^\circ}{244898\,\#}$$

$FS = 26 > 1.3$ OK (ETL 1110-2-256, PG. 20)

NORTH ABUTMENT STABILITY (CONT)

LOADING CONDITION CASE IIIb (CONT)

CHECK BEARING PRESSURE

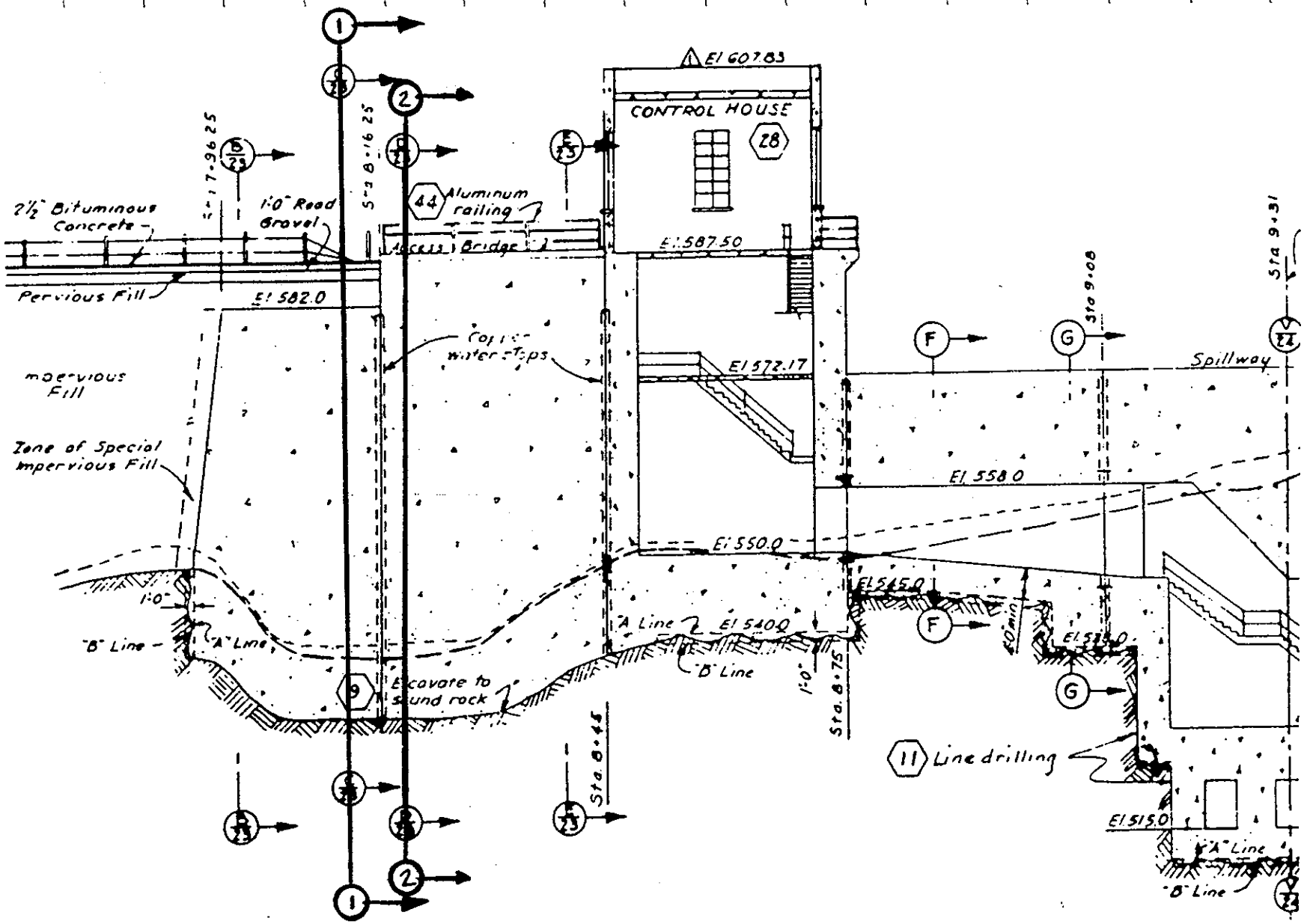
$$F = \frac{1122.276^K}{(13.25')(38')} \pm \frac{(1122.276^K)(7.62 - 6.63')(6.63')}{\frac{1}{12}(38')(13.25')^3}$$

$$= 2.23 \text{ KSF} \pm 1.00 \text{ KSF}$$

$F_{UPSTREAM} = 1.23$ KSF

OK ($F_{ALLOW} = 40$ KSF)

$F_{DOWNSTREAM} = 3.23$ KSF



SOUTH ABUTMENT

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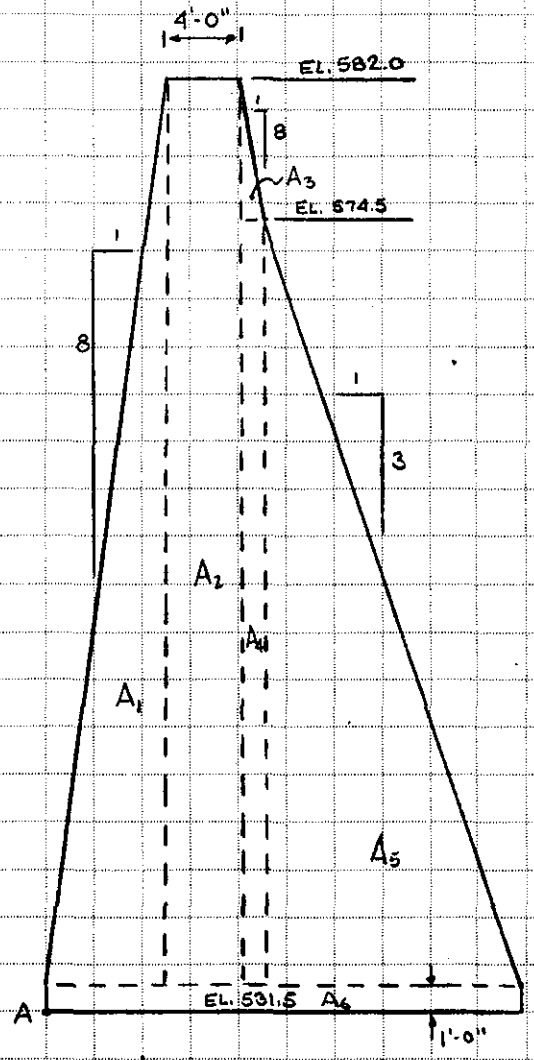
SOUTH ABUTMENT STABILITY

SECTION 1



SECTION	AREA (FT^2)	FORCE (K/FT)	VERT ARM (FT)	MOMENT	HORIZ. ARM (FT)	MOMENT
A_1	$\frac{1}{2}(6.188)(49.5) = 153.141$	22.971	17.5	401.993	4.125	94.755
A_2	$(4)(49.5) = 198.0$	29.7	25.75	764.775	8.188	243.169
A_3	$\frac{1}{2}(0.938)(7.5) = 3.516$	0.527	45.5	23.994	10.50	5.534
A_4	$(0.938)(42) = 39.375$	5.906	22.0	129.932	10.656	62.936
A_5	$\frac{1}{2}(14)(42) = 294.0$	44.1	15.0	661.50	15.792	696.413
A_6	$1(25.125) = 25.125$	3.769	0.5	1.884	12.563	47.348
		106.83 K/FT	18.57 FT	1983.06 K'/FT	10.77	1150.16 K'/FT

PRODUCT 204-1 NEBS Inc., Groton, Mass. 01471.

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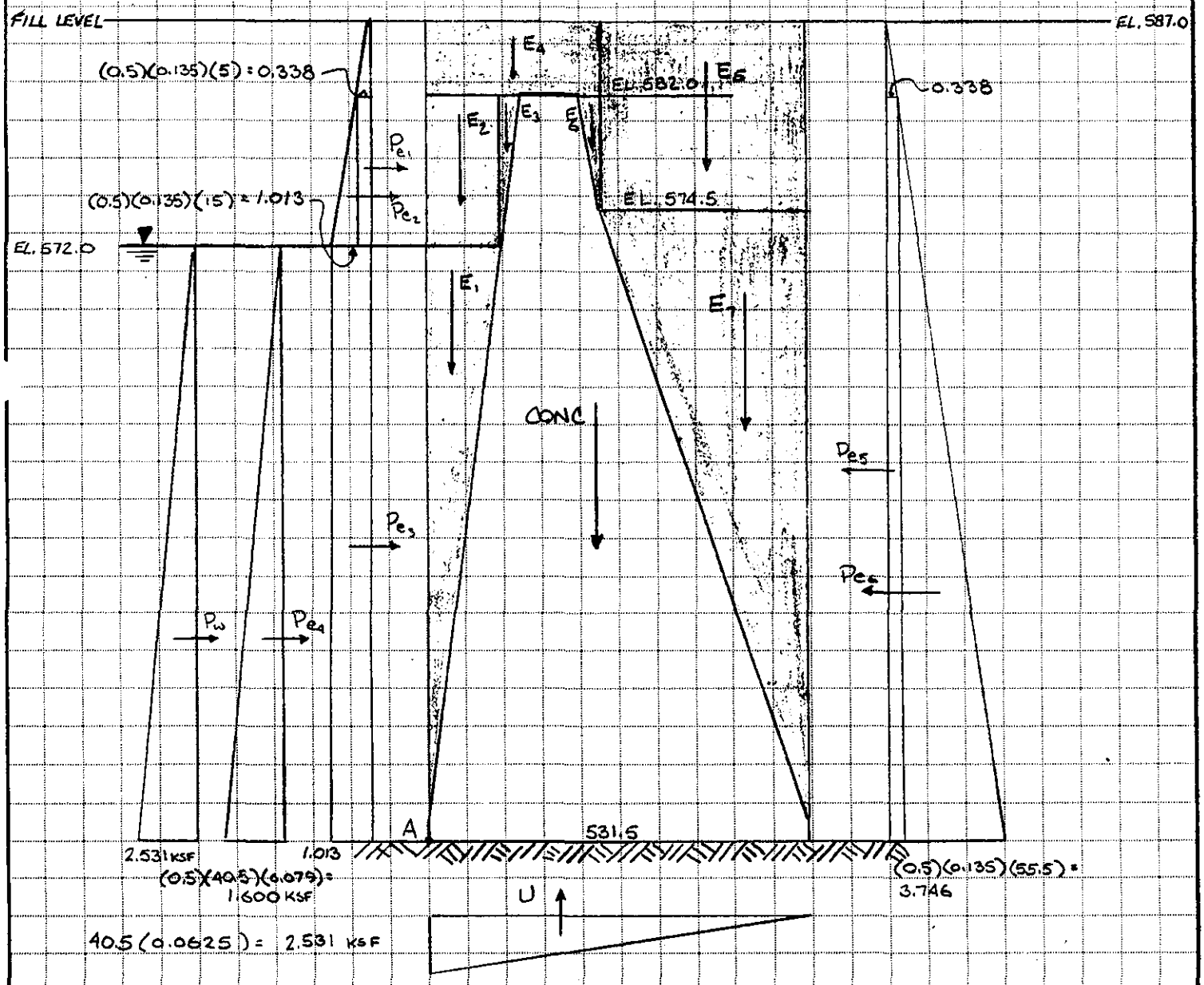
SOUTH ABUTMENT STABILITY (CONT)

SECTION 1

LOADING CONDITION CASE I - USUAL FLOOD LOADING



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SOUTH ABUTMENT STABILITY (CONT.)

SECTION ①

LOADING CONDITION CASE I (CONT)

ITEM	FORCE (K/FT)	ARM (FT)	MOMENT (FT-K/FT)
CONC	106.83 ↓		1150.16
E_1	$\frac{1}{2}(4.938)(39.5)(0.141) = 13.75$ ↓	1.65	22.63
E_2	$(4.938)(10)(0.135) = 6.67$ ↓	2.47	16.47
E_3	$\frac{1}{2}(1.25)(10)(0.135) = 0.84$ ↓	5.35	4.50
E_4	$(11.126)(5)(0.135) = 7.50$ ↓	5.56	41.72
E_5	$(14)(12.5)(0.135) = 23.63$ ↓	18.13	428.29
E_6	$\frac{1}{2}(0.938)(7.5)(0.135) = 0.47$ ↓	10.81	5.08
E_7	$\frac{1}{2}(14)(42)(0.135) = 39.69$ ↓	20.46	811.99
U	$\frac{1}{2}(25.125)(2.531) = 31.80$ ↑	8.38	-266.29
P_{e_1}	$(0.338)(10) = 3.38$ →	45.5	153.79
P_{e_2}	$\frac{1}{2}(1.013-0.338)(10) = 3.38$ →	43.83	148.16
P_{e_3}	$(1.013)(40.5) = 41.03$ →	20.25	830.86
P_{e_4}	$\frac{1}{2}(1.600)(40.5) = 32.40$ →	13.50	437.40
P_{e_5}	$(0.338)(50.5) = 17.07$ ←	25.25	-431.02
P_{e_6}	$\frac{1}{2}(3.746-0.338)(50.5) = 86.05$ ←	16.83	-1448.22
P_w	$\frac{1}{2}(2.531)(40.5) = 51.25$ →	13.50	691.88
	$\Sigma V = 167.58$ K/FT, $\Sigma H = 28.32$ K/FT		$\Sigma M = 2597.4$

CHECK OVERTURNING - REF. EM 1110-2-2501, PG. 17

$\Sigma M / \Sigma V = 2597.4 / 167.58 = 15.5'$

$8.38 < 15.5 < 16.8$ (OK) RESULTANT WITHIN MIDDLE 1/3
(EM 1110-2-2502)

SOUTH ABUTMENT STABILITY (CONT.)

SECTION 1

LOADING CONDITION CASE I (CONT)

CHECK SLIDING - REF. ETL 1110-2-256

$$FS = \frac{(80\,PSI)(25.125\,FT)(144\,IN^2/FT^2) + (167580\,\#/FT)\,TAN\,26.56^\circ}{28320\,\#/FT}$$

$FS = 13.2 > 1.5$ OK (EM 1110-2-2501, PG. 26)

CHECK BEARING PRESSURE

$$f = \frac{167.58\,K/FT}{25.125\,FT} \pm \frac{(167.58\,K/FT)(15.5' - 12.56')(12.56')}{\frac{1}{12}(25.125')^3}$$

$= 6.67\,KSF \pm 4.68\,KSF$

$f_{UPSTREAM} = 1.99\,KSF$

OK ($f_{ALLOW} = 40\,KSF$)

$f_{DOWNSTREAM} = 11.35\,KSF$

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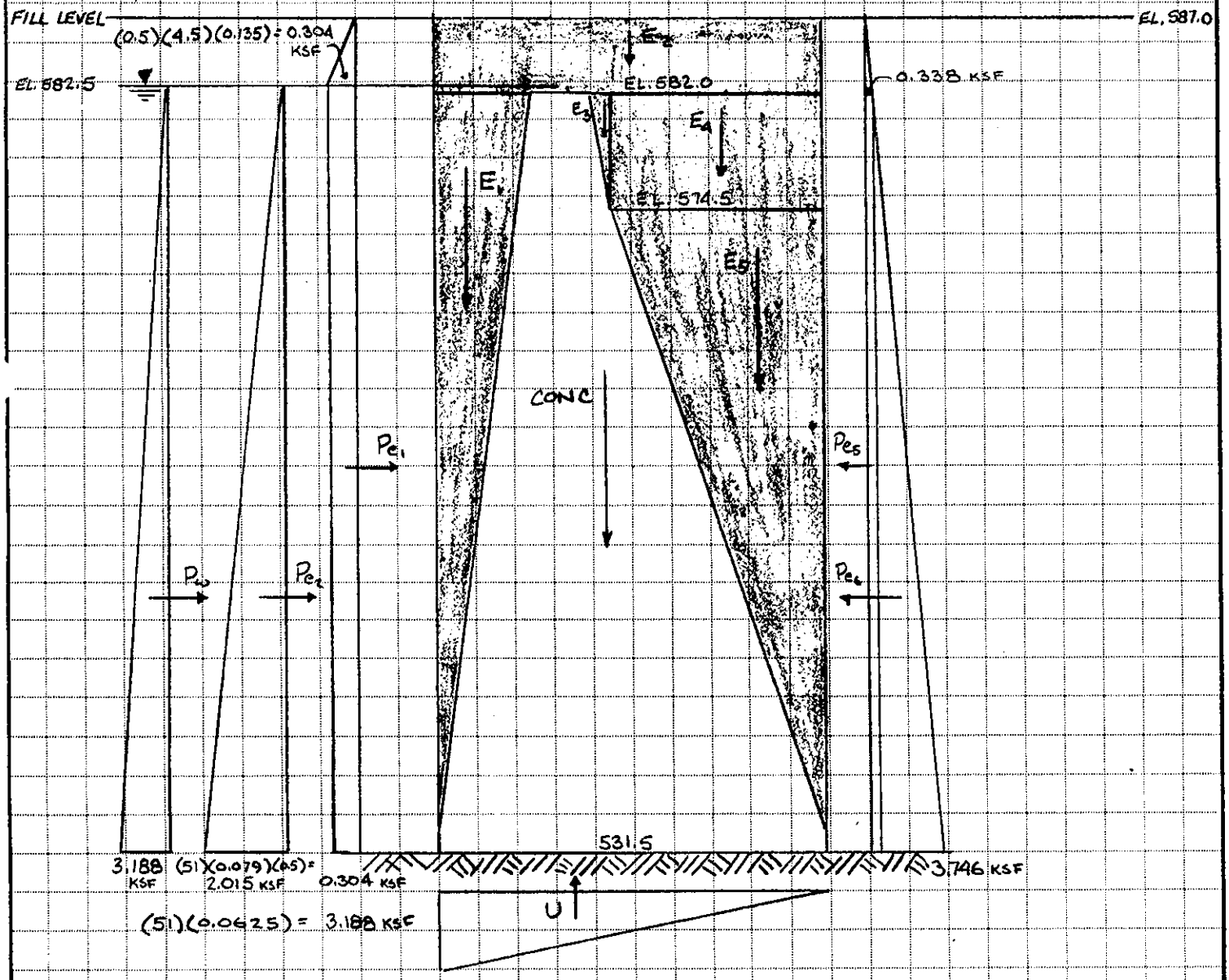
SOUTH ABUTMENT STABILITY (CONT)

SECTION 1

LOADING CONDITION CASE II · EXTREME FLOOD LOADING



SOUTH ABUTMENT STABILITY (CONT)

SECTION ①

LOADING CONDITION CASE II (CONT.)

ITEM	FORCE (K/FT)	ARM (FT)	MOMENT (FT-K/FT)
CONC	106.83 ↓		1150.16
E_1	$\frac{1}{2}(6.188)(49.5)(0.141) = 21.60$ ↓	2.06	44.55
E_2	$(5)(25.125)(0.135) = 16.96$ ↓	12.56	213.06
E_3	0.47 ↓	10.81	5.08
E_4	$(7.5)(14)(0.135) = 14.18$ ↓	18.13	257.01
E_5	39.69 ↓	20.46	811.99
U	$\frac{1}{2}(3.188)(25.125) = 40.04$ ↑	8.38	-335.36
P_{e_1}	$(0.304)(50.5) = 15.35$ →	25.25	387.59
P_{e_2}	$\frac{1}{2}(2.015)(50.5) = 50.88$ →	16.83	856.48
P_{e_5}	17.07 ←	25.25	-431.02
P_{e_6}	86.05 ←	16.83	-1448.22
P_w	$\frac{1}{2}(3.188)(50.5) = 80.50$ →	16.83	1355.08
	$\Sigma V = 159.69$ K/FT, $\Sigma H = 43.61$ K/FT		$\Sigma M = 2866.4$

CHECK OVERTURNING - REF. EM 1110-2-2501, PG. 17

$\Sigma M / \Sigma V = 2866.4 / 159.69 = 17.95$

$8.38 < 17.95 > 16.75$ NG

$0 < 17.95 < 25.125$ OK

IF OTHER CONDITIONS ARE SATISFIED
(EM 1110-2-2502)

CHECK SLIDING - REF. ETL 1110-2-256

$$FS = \frac{(80\ \text{PSI})(25.125\ \text{ft})(144\ \text{in}^2/\text{ft}^2) + (159690\ \#/\text{ft})\ \text{TAN}\ 26.56^\circ}{43610\ \#/\text{FT}}$$

$FS = 8.5 > 1.5$ OK (EM 1110-2-2502)

SOUTH ABUTMENT STABILITY (CONT)

SECTION 1

LOADING CONDITION CASE II (CONT)

CHECK BEARING PRESSURE

$$f = \frac{2V}{3e} = \frac{2(159.69\ K/FT)}{3(7.175\ FT)}$$

$$f = 14.8\ KSF \quad OK \quad (f_{ALLOW} = 40\ KSF)$$

$$e = (L/2) - e$$

$$= \left(\frac{25.125}{2}\right) - \left(17.55 - \frac{25.125}{2}\right)$$

$$= 7.175\ FT$$

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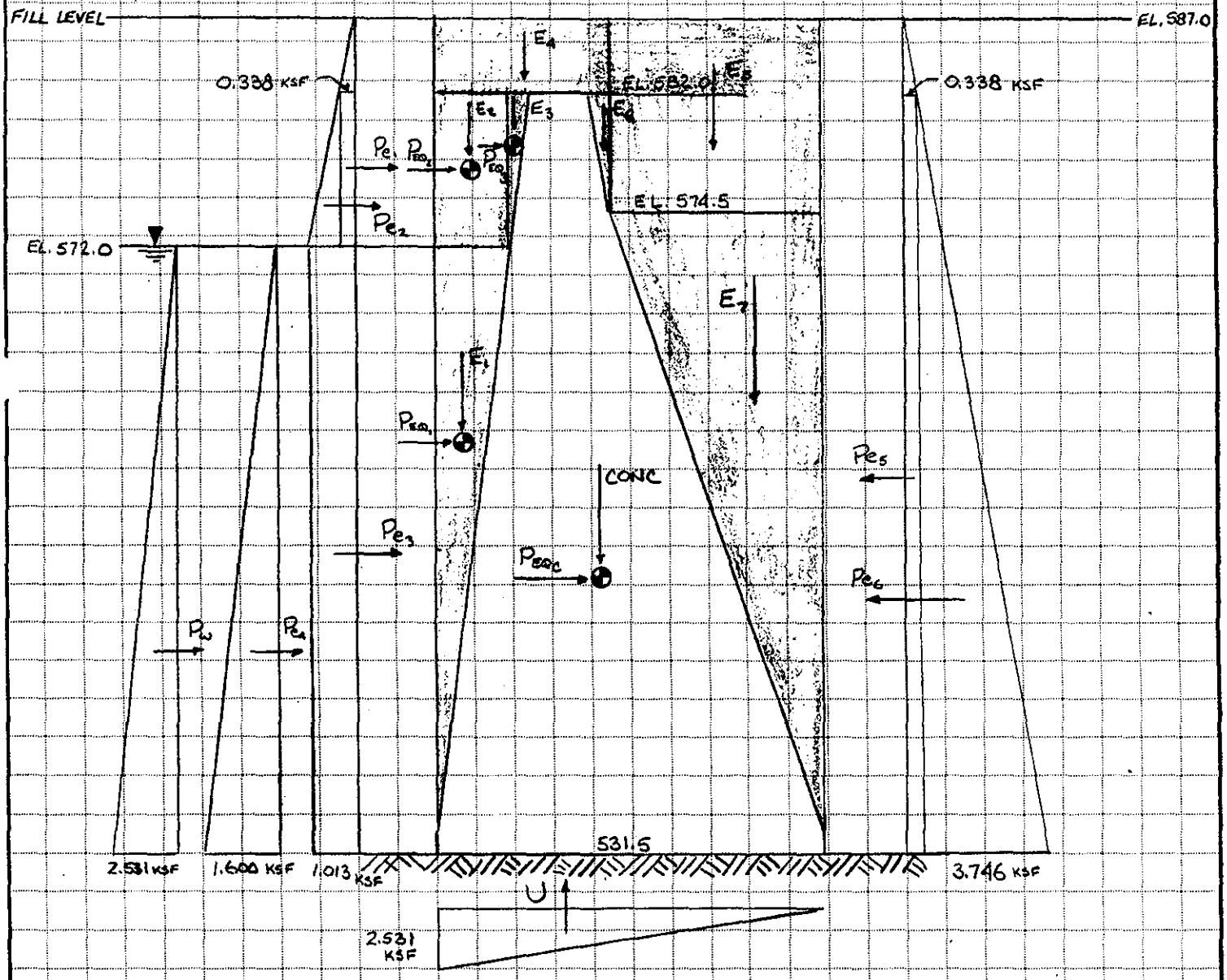
SOUTH ABUTMENT STABILITY (CONT)

SECTION 1

LOADING CONDITION CASE III - EARTHQUAKE LOADING



SOUTH ABUTMENT STABILITY (CONT.)

SECTION 1

LOADING CONDITION CASE III (CONT)

ITEM	FORCE (K/FT)	ARM (FT)	MOMENT (FT-K/FT)
CONC	106.83 ↓		1150.16
E.	13.75 ↓		22.63
E_2	6.67 ↓		16.47
E_3	0.84 ↓		4.50
E_4	7.50 ↓		41.72
E_5	23.63 ↓		428.29
E_6	0.47 ↓		5.08
E_7	39.69 ↓		811.99
U	31.80 ↑		-266.29
P_{e_1}	3.38 →		153.79
P_{e_2}	3.38 →		148.16
P_{e_3}	41.03 →		830.86
P_{e_4}	32.40 →		437.40
P_{e_5}	17.07 ←		-431.02
P_{e_6}	86.05 ←		-1448.22
P_w	51.25 →		691.88
P_{EQ_c}	10.68 →	18.57	198.33
P_{EQ_1}	1.38 →	27.33	37.72
P_{EQ_2}	0.67 →	45.50	30.49
P_{EQ_3}	0.08 →	47.17	3.77
	$\Sigma V = 167.58$ K/FT		$\Sigma M = 2867.71$ FT-K/FT

$\Sigma H = 41.13$ K/FT

SOUTH ABUTMENT STABILITY (CONT.)

SECTION 1

LOADING CONDITION CASE III (CONT)

CHECK OVERTURNING

$\Sigma M / \Sigma V = 2867.71 / 167.58 = 17.1'$

$8.375 < 17.1 > 16.75$ NG

$0 < 17.1 < 25.125$ OK

IF OTHER CONDITIONS ARE SATISFIED
(EM 1110-2-2502)

CHECK SLIDING

$$FS = \frac{(80\ PSI)(25.125\ FT)(144\ IN^2/FT^2) + (167580\ \#/FT)\ TAN\ 26.56^\circ}{41130\ \#/FT}$$

$FS = 9.1 > 1.5$ OK (EM 1110-2-2502)

CHECK BEARING PRESSURE

$$f = \frac{2V}{3e}$$

$$e = \left(\frac{25.125}{2}\right) - \left(17.1 - \frac{25.125}{2}\right) = 8.025$$

$$= \frac{2(167.58\ \#/FT)}{3(8.025\ FT)}$$

$= 13.9$ KSF OK ($f_{ALL} = 40$ KSF)

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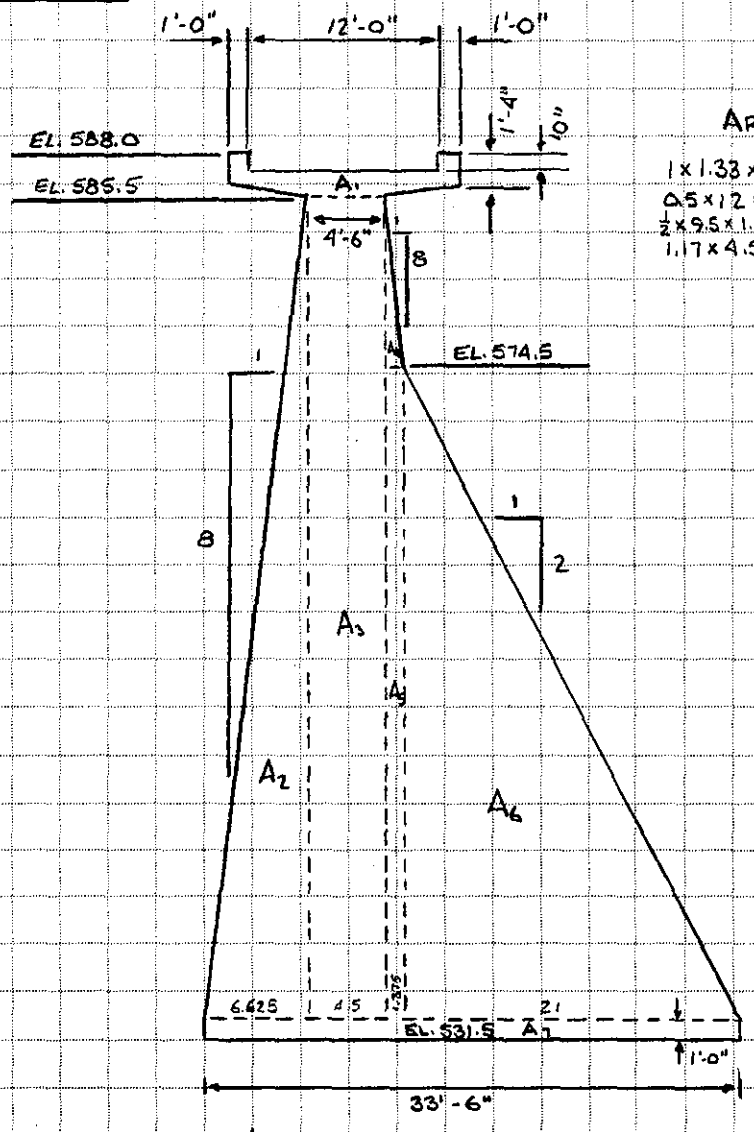
SOUTH ABUTMENT STABILITY (CONT)

SECTION 2



AREA A1

	AREA	ARM	MOMENT
1 x 1.33 x 2 =	2.67	1.83	4.89
0.5 x 12 =	6.00	1.42	8.50
½ x 9.5 x 1.17 =	5.54	0.77	4.31
1.17 x 4.5 =	5.25	0.58	3.06
	19.458	1.067	20.762

ITEM	AREA (FT²)	FORCE	VERT ARM	MOMENT	HORIZ ARM	MOMENT
A1	19.458	2.919	55.067	160.741	8.875	25.906
A2	½(53)(6.625) = 175.563	26.334	18.667	491.568	4.417	116.317
A3	(4.5)(53) = 238.50	35.775	27.50	983.813	8.875	317.503
A4	½(1.375)(11) = 7.563	1.134	46.667	52.920	11.583	13.135
A5	(1.375)(42) = 57.75	8.663	22.0	190.586	11.813	102.336
A6	½(2.1)(42) = 44.1.0	66.150	15.0	992.250	19.500	1289.925
A7	(33.5)(1) = 33.50	5.025	0.5	2.513	16.750	84.169
		146.000	19.688	2874.391	13.351	1949.291

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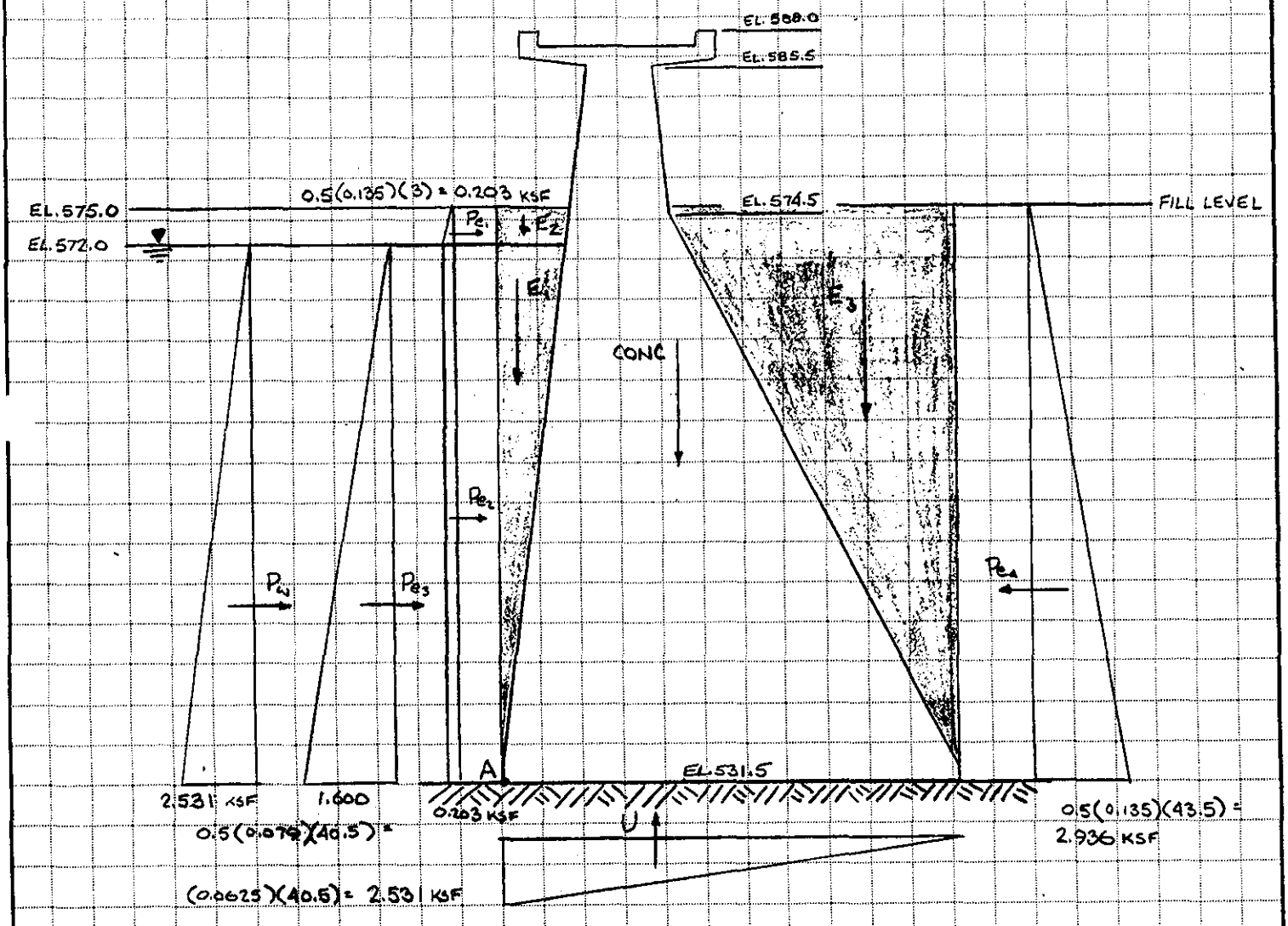
SOUTH ABUTMENT STABILITY (CONT)

SECTION ②

LOADING CONDITION CASE I USUAL FLOOD LOADING



SOUTH ABUTMENT STABILITY (CONT)

SECTION ②

LOADING CONDITION CASE I (CONT)

ITEM	FORCE (K/FT)	ARM (FT)	MOMENT (FT·K/FT)
CONC	146.00 ↓		1949.29
E_1	$\frac{1}{2}(4.9375)(39.5)(0.141) = 13.75$ ↓	1.65	22.69
E_2	$\left(\frac{5.3125+4.9375}{2}\right)(3)(0.135) = 2.08$ ↓	2.56	5.33
E_3	$\frac{1}{2}(21.25)(42.5)(0.135) = 60.96$ ↓	26.42	1610.56
U	$\frac{1}{2}(2.531)(33.5) = 42.42$ ↑	11.17	-473.83
P_{e_1}	$\frac{1}{2}(0.203)(3) = 0.30$ →	41.50	12.45
P_{e_2}	$(0.203)(40.5) = 8.22$ →	20.25	166.46
P_{e_3}	$\frac{1}{2}(1.600)(40.5) = 32.40$ →	13.50	437.40
P_{e_4}	$\frac{1}{2}(2.936)(43.5) = 63.86$ ←	14.50	-925.97
P_w	$\frac{1}{2}(2.531)(40.5) = 51.25$ →	13.50	691.88
	$\Sigma V = 180.37$ K/FT, $\Sigma H = 28.31$ K/FT		3496.26 FT·K/FT

CHECK OVERTURNING

$\Sigma M / \Sigma V = 3496.26 / 180.37 = 19.4'$

$11.17 < 19.4 < 22.3$ OK RESULTANT WITHIN MIDDLE $\frac{1}{3}$
(EM 1110-2-2502)

CHECK SLIDING

$$FS = \frac{(80\ \text{PSI})(33.5\ \text{FT})(144\ \text{IN}^2/\text{FT}^2) + (180370\ \#/\text{FT})\ \text{TAN}\ 26.56^\circ}{28310\ \#/\text{FT}}$$

$FS = 16.8 > 1.5$ OK (EM 1110-2-2502)

SOUTH ABUTMENT STABILITY (CONT)

SECTION 2

LOADING CONDITION CASE I (CONT)

CHECK BEARING PRESSURE

$$f = \frac{180.37\ ^{K}/_{FT}}{33.5\ FT} + \frac{(180.37\ ^{K}/_{FT})(19.4 - 16.75)(16.75)}{\frac{1}{12}(33.5)^3}$$

$$= 5.38\ KSF + 2.56\ KSF$$

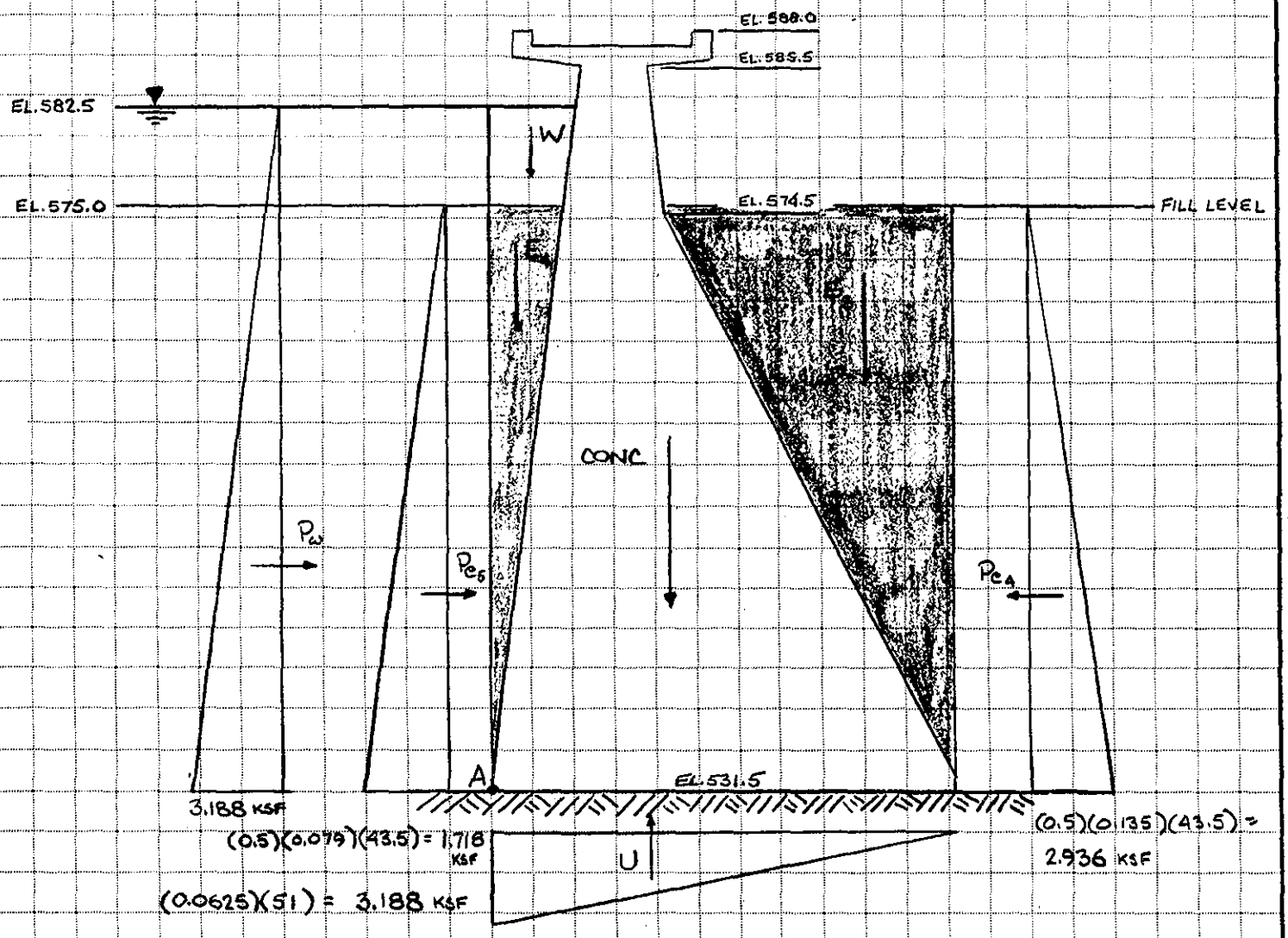
$f_{DOWNSTREAM} = 7.94$ KSF (OK) ($f_{ALLOW} = 40$ KSF)

$f_{upstream} = 2.82$ ksf

SOUTH ABUTMENT STABILITY (CONT)

SECTION ②

LOADING CONDITION CASE II - EXTREME FLOOD LOADING



SOUTH ABUTMENT STABILITY (CONT.)

SECTION ②

LOADING CONDITION CASE II (CONT)

ITEM	FORCE (K/FT)	ARM (FT)	MOMENT (FT·K/FT)
CONC	146.00 ↓		1949.29
E_3	60.96 ↓		1610.56
E_4	$\frac{1}{2}(5.3125)(42.5)(0.141) = 15.92$ ↓	1.77	28.18
W	$\frac{1}{2}(6.25+5.3125)(7.5)(0.0625) = 2.71$ ↓	2.89	7.83
U	$\frac{1}{2}(3.188)(33.5) = 53.40$ ↑	11.17	-596.48
P_{e4}	63.86 ←		-925.97
P_{es}	$\frac{1}{2}(1.718)(43.5) = 37.37$ →	14.50	541.87
P_{ws}	$\frac{1}{2}(3.188)(51) = 81.29$ →	17.00	1381.93
	$\Sigma V = 171.92$ K/FT, $\Sigma H = 54.80$ K/FT		$\Sigma M = 3997.21$ FT·K/FT

CHECK OVERTURNING

$\Sigma M / \Sigma V = 3997.21 / 171.92 = 23.25'$

11.17 < 23.25 > 22.3 NG

0 < 23.25 < 33.5 OK

IF OTHER CONDITIONS ARE SATISFIED

(EM 1110-2-2502)

CHECK SLIDING

$$FS = \frac{(80\ PSI)(33.5^{IN})(144\ IN^2/FT^2) + (171920\#/FT)\tan 26.56°}{54800}$$

FS = 8.6 > 1.5 OK (EM 1110-2-2502)

SOUTH ABUTMENT STABILITY (CONT)

SECTION ②

LOADING CONDITION CASE II (CONT.)

CHECK BEARING PRESSURE

$$f = \frac{2V}{3e}$$

$$e = \left(\frac{33.5}{2}\right) - \left(23.25 - \frac{33.5}{2}\right) = 10.25 \text{ FT}$$

$$= \frac{2(171.92 \text{ K/FT})}{3(10.25 \text{ FT})}$$

$f = 11.18$ KSF OK ($F_{ALLOW} = 40$ KSF)

$f_{upstream} = 0.0$ ksf

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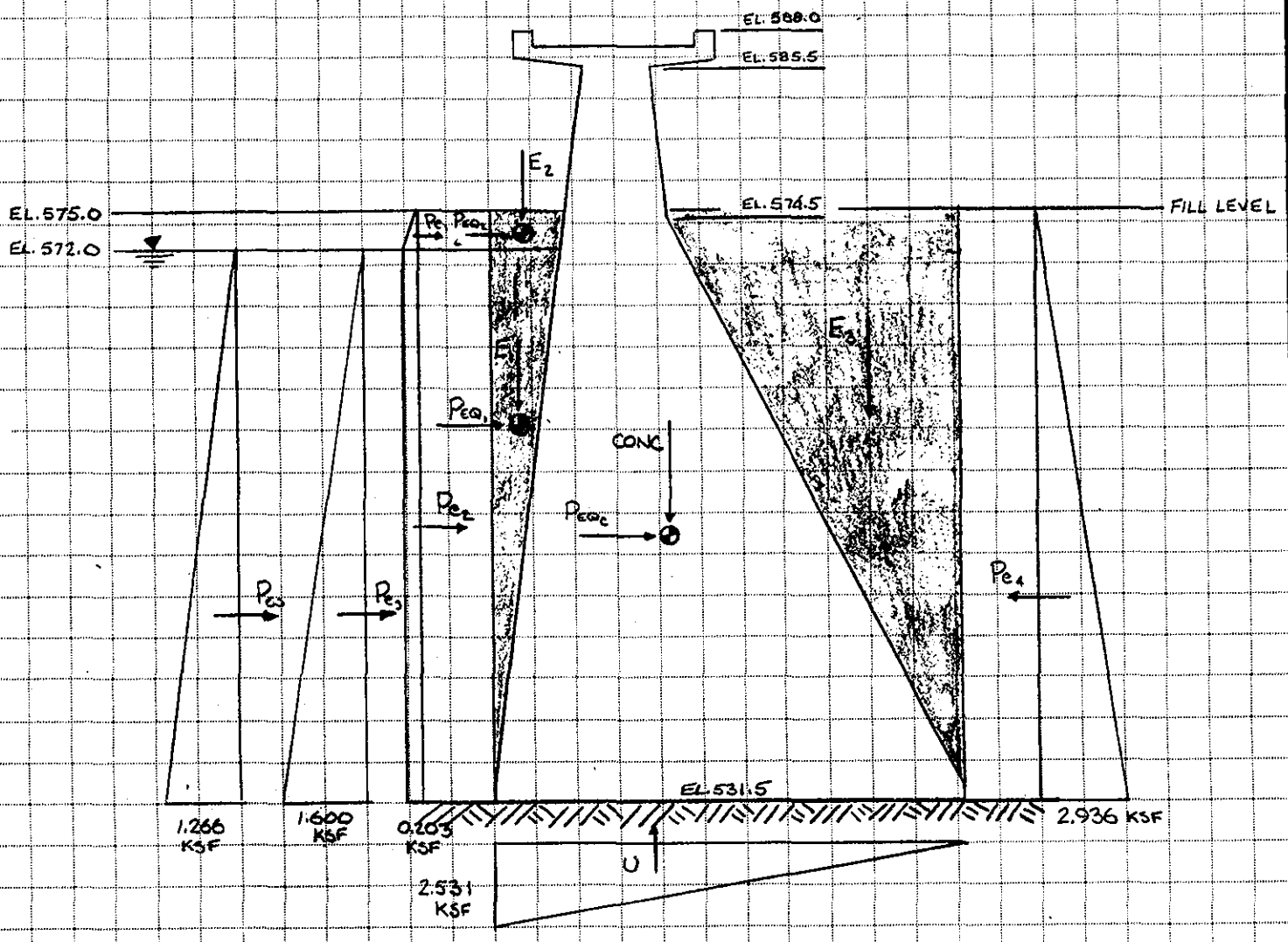
SOUTH ABUTMENT STABILITY (CONT)

SECTION ②

LOADING CONDITION CASE III - EARTHQUAKE LOADING



SOUTH ABUTMENT STABILITY (CONT)

SECTION ②

LOADING CONDITION CASE III (CONT)

ITEM	FORCE (K/FT)	ARM (FT)	MOMENT (FT-K/FT)
CONC	146.00 ↓		1949.29
E_1	13.75 ↓		22.69
E_2	2.08 ↓		5.33
E_3	60.96 ↓		1610.56
U	42.42 ↑		-473.83
P_{e_1}	0.30 →		12.45
P_{e_2}	8.22 →		166.46
P_{e_3}	32.40 →		437.40
P_{e_4}	63.86 ←		-925.97
P_s	51.25 →		691.88
P_{EQ_c}	14.60 →	19.69	287.47
P_{EQ_1}	1.38 →	27.33	37.72
P_{EQ_2}	0.21 →	42.02	8.82
	$\Sigma V = 180.37$ K/FT		$\Sigma M = 3830.27$

$\Sigma H = 44.50$ K/FT

CHECK OVERTURNING

$\Sigma M / \Sigma V = 3830.27 / 180.37 = 21.2'$

$11.2 < 21.2 < 22.3$ OK RESULTANT WITHIN MIDDLE 1/3
(EM 1110-2-2502)

SOUTH ABUTMENT STABILITY (CONT)

SECTION 2

LOADING CONDITION CASE III (CONT)

CHECK SLIDING

$$FS = \frac{(80\ PSL)(33.5\ FT)(144\ IN^2/FT^2) + (180370\ \#/FT)\ TAN\ 26.56^\circ}{44500\ \#/FT}$$

$FS = 10.7 > 1.5$ OK (EM 1110-2-2502)

CHECK BEARING PRESSURE

$$f = \frac{180.37}{33.5} + \frac{(180.37)(21.2 - 16.75)(16.75)}{\frac{1}{12}(33.5)^3}$$

$= 5.38\ KSF + 4.29\ KSF$

$f_{UPSTREAM} = 9.67\ KSF$ OK ($f_{ALLOW} = 40\ KSF$)

$f_{downstream} = 1.09\ ksf$

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JOB: WESTVILLE DAM STABILITY ANALYSIS
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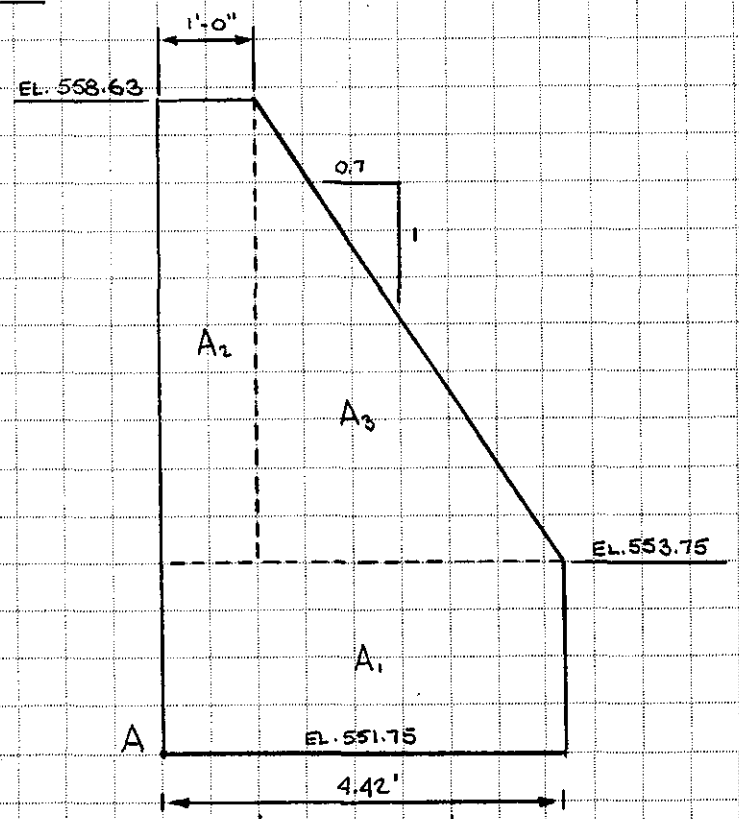
SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY)

SECTION 1



ITEM	AREA FT²	FORCE K/FT	X-X AXIS ARM	X-X AXIS MOMENT	Y-Y AXIS ARM	Y-Y AXIS MOMENT
A_1	(2)(4.42) = 8.84	1.33	2.21	2.93	1.00	1.33
A_2	(1)(4.88) = 4.88	0.73	0.50	0.37	4.44	3.25
A_3	½(3.42)(4.88) = 8.34	1.25	2.14	2.68	3.62	4.54
		3.31 K/FT	1.8 FT	5.98 FT-K/FT	2.76 FT	9.12 FT-K/FT

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SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY) (CONT)

SECTION 1

LOADING CONDITION CASE I - USUAL LOADING

PERMANENT POOL ELEVATION - EL. 525.0

BELOW BOTTOM OF WALL

$E_1 = (0.135)\frac{1}{2}(2.72)(1.09)$

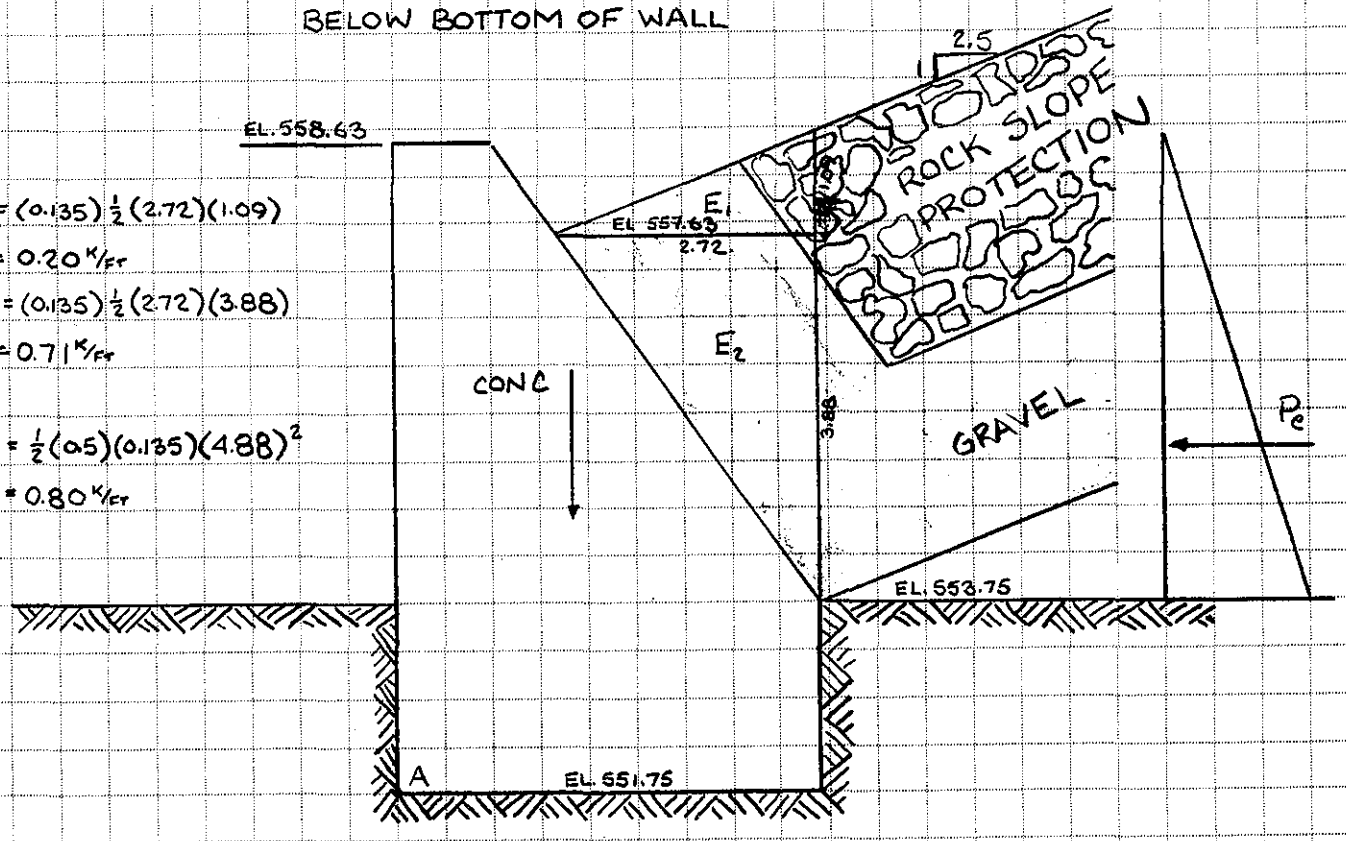
$= 0.20^{K}/_{FT}$

$E_2 = (0.135)\frac{1}{2}(2.72)(3.88)$

$= 0.71^{K}/_{FT}$

$P_e = \frac{1}{2}(0.5)(0.135)(4.88)^2$

$= 0.80^{K}/_{FT}$



ITEM	FORCE	ARM	MOMENT
CONC	3.31 ↓		5.98
E_1	0.20 ↓	3.51	0.70
E_2	0.71 ↓	3.51	2.49
P_e	-0.80 ←	3.62	-2.90
	$\Sigma V = 4.22^{K}/_{FT}$		$\Sigma M = 6.27^{FT\cdot K}/_{FT}$

$\Sigma H = -0.80^{K}/_{FT}$

SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY) (CONT)

SECTION (1)

LOADING CONDITION CASE I (CONT)

CHECK OVERTURNING

$\Sigma M / \Sigma V = 6.27 / 4.22 = 1.49'$

$1.47' < 1.49' < 2.95'$ (OK) RESULTANT WITHIN MIDDLE THIRD

CHECK SLIDING

$$FS = \frac{(80\ PSI)(4.42')(144\ IN^2/FT^2) + (4220\ \#/FT)\ TAN\ 26.56°}{800\ \#/FT}$$

$FS = 66 > 1.5$ (OK)

CHECK BEARING PRESSURE

$$f = \frac{4.22}{4.42} \pm \frac{(4.22)(1.49 - 2.21)(2.21)}{\frac{1}{12}(4.42)^3}$$

$= 0.95\ KSF \pm 0.93\ KSF$

$f_{MAX} = 1.88\ KSF$

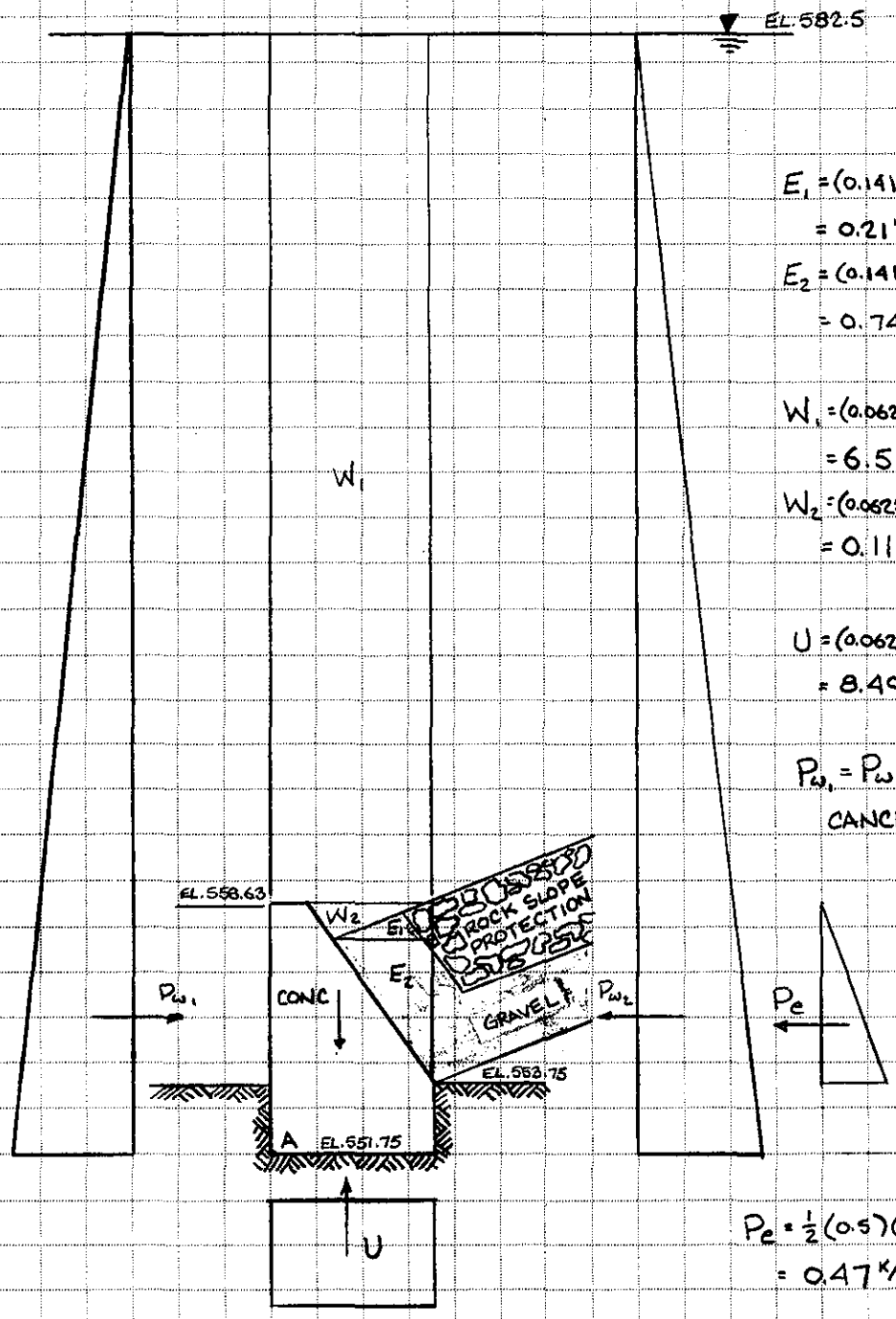
$f_{MIN} = 0.02\ KSF$

SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY) (CONT)

SECTION 1

LOADING CONDITION CASE II EXTREME LOADING

MAXIMUM FLOOD ELEVATION - EL. 582.5



$E_1 = (0.141)\frac{1}{2}(2.72)(1.09)$
$= 0.21\ ^{K}/_{FT}$

$E_2 = (0.141)\frac{1}{2}(2.72)(3.88)$
$= 0.74\ ^{K}/_{FT}$

$W_1 = (0.0625)(4.42)(23.87)$
$= 6.59\ ^{K}/_{FT}$

$W_2 = (0.0625)\frac{1}{2}(1)(3.42)$
$= 0.11\ ^{K}/_{FT}$

$U = (0.0625)(30.75)(4.42)$
$= 8.49\ ^{K}/_{FT}$

$P_{\omega_1} = P_{\omega_2}$
CANCEL OUT

$P_e = \frac{1}{2}(0.5)(0.079)(4.88)^2$
$= 0.47\ ^{K}/_{FT}$

SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY) (CONT)

SECTION ①

LOADING CONDITION CASE II (CONT)

ITEM	FORCE	ARM	MOMENT
CONC	3.31		5.98
E_1	0.21	3.51	0.74
E_2	0.74	3.51	2.60
W_1	6.59	2.21	14.56
W_2	0.11	2.37	0.26
U	-8.49	2.21	-18.76
P_e	-0.47 ←	3.63	-1.71
$P_{w_1} = P_{w_2}$	CANCEL	-	-
	$\Sigma V = 2.47$ K/FT		$\Sigma M = 3.67$ FT-K/FT
	$\Sigma H = -0.47$ K/FT		

CHECK OVERTURNING

$\Sigma M / \Sigma V = 3.67 / 2.47 = 1.49$

$1.47' < 1.49' < 2.95'$ OK RESULTANT WITHIN MIDDLE THIRD

CHECK SLIDING

$$FS = \frac{(80\ PSI)(4.42')(144\ IN^2/FT^2) + (2470\ \#/FT)(TAN\ 26.56°)}{470\ \#/FT}$$

$FS = 111 >> 1.5$ OK

SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY) (CONT)

SECTION ①

LOADING CONDITION CASE II (CONT)

CHECK BEARING PRESSURE

$$f = \frac{2.47}{4.42} \pm \frac{2.47(1.49-2.21)(2.21)}{\frac{1}{12}(4.42)^3}$$

$$= 0.56 \text{ KSF} \pm 0.55 \text{ KSF}$$

$f_{MAX} = 1.11$ KSF

OK ($f_{ALLOW} = 40$ KSF)

$f_{MIN} = 0.01$ KSF

SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY) (CONT)

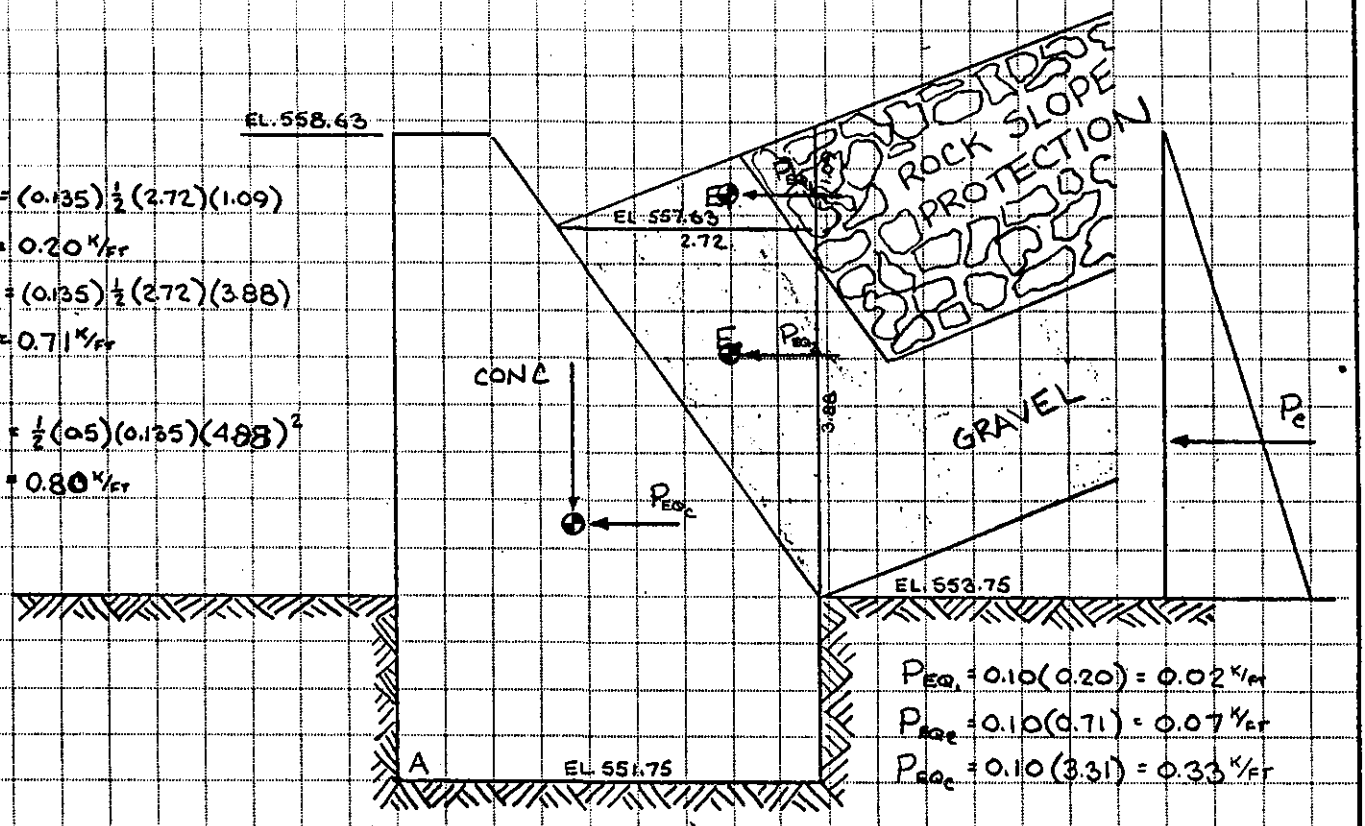
SECTION 1

LOADING CONDITION CASE III - EARTHQUAKE LOADING

$E_1 = (0.135)\frac{1}{2}(2.72)(1.09)$
$= 0.20^{K}/_{FT}$

$E_2 = (0.135)\frac{1}{2}(2.72)(3.88)$
$= 0.71^{K}/_{FT}$

$P_e = \frac{1}{2}(0.5)(0.135)(4.88)^2$
$= 0.80^{K}/_{FT}$



$P_{EQ_1} = 0.10(0.20) = 0.02^{K}/_{FT}$
$P_{EQ_2} = 0.10(0.71) = 0.07^{K}/_{FT}$
$P_{EQ_C} = 0.10(3.31) = 0.33^{K}/_{FT}$

ITEM	FORCE		ARM	MOMENT
CONC	3.31	V		5.98
E_1	0.20	V	3.51	0.70
E_2	0.71	V	3.51	2.49
P_e	-0.80	H	3.63	-2.90
P_{EQ_C}	-0.33	H	2.76	-0.91
P_{EQ_1}	-0.02	H	6.24	-0.12
P_{EQ_2}	-0.07	H	4.59	-0.32
	$\Sigma V = 4.22^{K}/_{FT}$			$\Sigma M = 4.92^{FT\text{-}K}/_{FT}$
	$\Sigma H = -1.22^{K}/_{FT}$			

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SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY) (CONT)

SECTION ①

LOADING CONDITION CASE III (CONT)

CHECK OVERTURNING

$\Sigma M / \Sigma V = 4.92 / 4.22 = 1.17'$

OK $1.17' < 4.42'$
RESULTANT WITHIN BASE OK

CHECK SLIDING

$$FS = \frac{(80\ PSI)(4.42\ FT)(144\ IN^2/FT^2) + (4220\ \#/FT)\ TAN\ 26.56^\circ}{1220\ \#/FT}$$

$FS = 43 > 1.5$ OK

CHECK BEARING PRESSURE

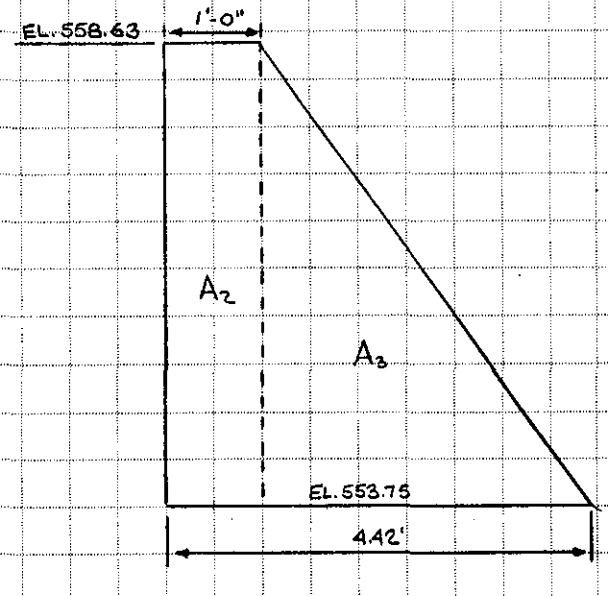
$$f_{max} = \frac{2V}{3e} \qquad e = 1.17'$$

$$f_{max} = \frac{2(4.22^k)}{3(1.17')} = 2.40\ ksf \qquad (f_{allow} = 40\ ksf)$$

OK

SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY) (CONT)

SECTION ② (FIELD CONDITIONS? SEE PERIODIC INSPECTION REPORT NO. 1, WESTVILLE LAKE, PG. III-11, PICTURE 17)



ITEM	AREA FT^2	FORCE K/FT	X-X AXIS ARM	X-X AXIS MOMENT	Y-Y AXIS ARM	Y-Y AXIS MOMENT
A_2	(1)(4.88) = 4.88	0.73	0.50	0.37	2.44	1.78
A_3	$\frac{1}{2}$(3.42)(4.88) = 8.34	1.25	2.14	2.68	1.63	2.04
		1.98	1.54	3.05	1.93	3.82

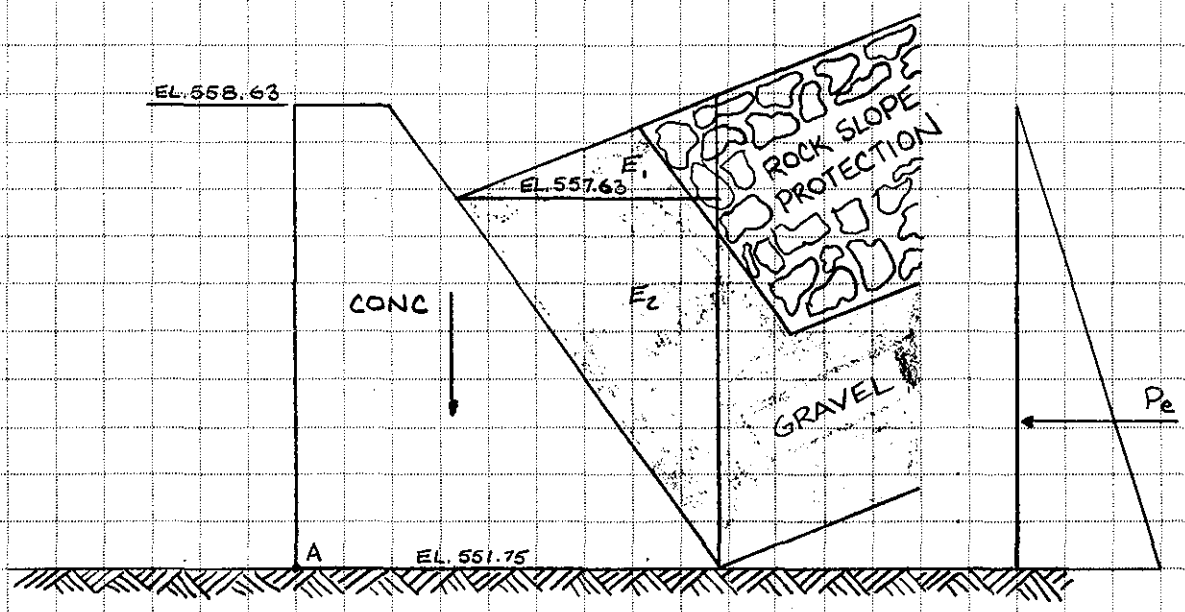
SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY) (CONT)

SECTION ②

LOADING CONDITION CASE I - USUAL LOADING

PERMANENT POOL ELEVATION - EL. 525.0

BELOW BOTTOM OF WALL



ITEM	FORCE		ARM	MOMENT
CONC	1.98	V		3.05
E_1	0.20	V	3.51	0.70
E_2	0.71	V	3.51	2.49
P_e	-0.80	H	3.63	-2.90
	$\Sigma V = 2.89$ K/FT			$\Sigma M = 3.34$ FT-K/FT ✓

$\Sigma H = -0.80$ K/FT

SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY) (CONT)

SECTION ②

LOADING CONDITION CASE I (CONT)

CHECK OVERTURNING

$\Sigma M / \Sigma V = 3.34 / 2.89 = 1.16'$

$0 < 1.16' < 4.42'$
RESULTANT WITHIN BASE (ok)

CHECK SLIDING

$$FS = \frac{(80\,PSI)(4.42\,FT)(144\,IN^2/FT^2) + (2890\,\#/FT)\tan 26.56^\circ}{800\,\#/FT}$$

$FS = 65 > 1.5$ (OK)

CHECK BEARING PRESSURE

$$f_{max} = \frac{2V}{3e}$$ where $e = 1.16$

$$f_{max} = \frac{2(2.89)}{3(1.16)} = 1.66\ ksf$$ ($f_{allow} = 40\ ksf$)

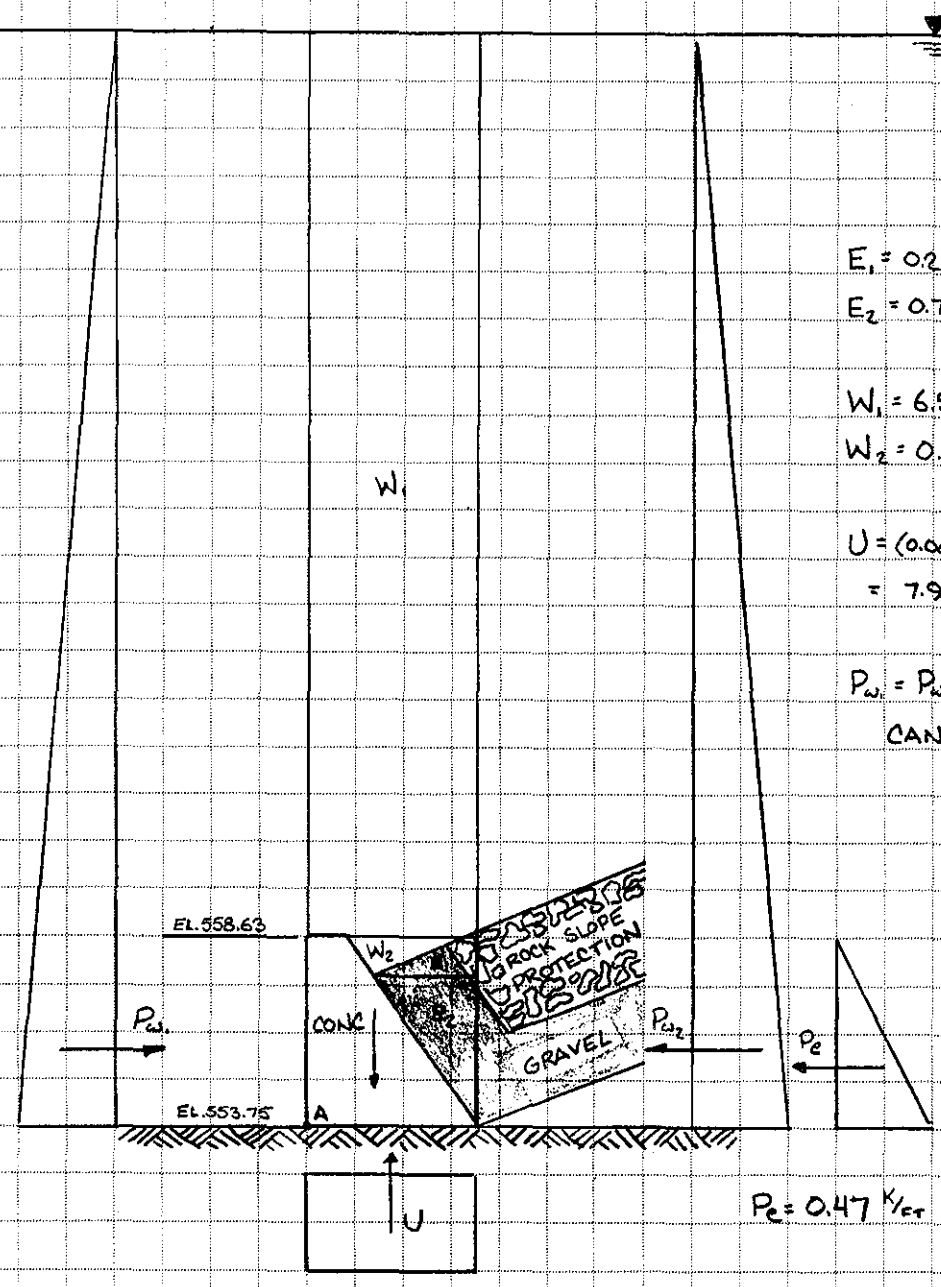
(ok)

SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY) (CONT)

SECTION ②

LOADING CONDITION CASE II - EXTREME LOADING

MAXIMUM FLOOD ELEVATION - EL. 582.5



$E_1 = 0.21$ K/FT
$E_2 = 0.74$ K/FT
$W_1 = 6.59$ K/FT
$W_2 = 0.11$ K/FT

SEE SECTION ① LOADING CONDITION CASE R2

$U = (0.0625)(28.75)(4.42)$
$= 7.94$ K/FT

$P_{w_1} = P_{w_2}$
CANCEL

$P_e = 0.47$ K/FT

SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY) (CONT)

SECTION ②

LOADING CONDITION CASE II (CONT)

ITEM	FORCE	ARM	MOMENT
CONC	1.98		3.05
E_1	0.21	3.51	0.74
E_2	0.74	3.51	2.60
W_1	6.59	2.21	14.56
W_2	0.11	2.37	0.26
U	-7.94	2.21	-17.55
P_e	-0.47 ←	1.63	-0.76
$P_{w_1} = P_{w_2}$	CANCEL	-	-
	$\Sigma V = 1.69$ K/FT		$\Sigma M = 2.90$ FT·K/FT
	$\Sigma H = -0.47$ K/FT		

CHECK OVERTURNING

$\Sigma M / \Sigma V = 2.90 / 1.69 = 1.72$

$1.47' < 1.72 < 2.95'$
RESULTANT WITHIN MIDDLE THIRD (OK)

CHECK SLIDING

$$FS = \frac{(80\ PSI)(4.42')(144\ IN^2/FT^2) + (1690\ \#/FT)\ TAN\ 26.56°}{470\ \#/FT}$$

$FS = 110 >> 1.5$ (OK)

SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY) (CONT)

SECTION ②

LOADING CONDITION CASE II (CONT)

CHECK BEARING PRESSURE

$$f = \frac{1.69^{K/FT}}{4.42\ FT} \pm \frac{(1.69^{K/FT})(1.72-2.21)(2.21)}{\frac{1}{12}(4.42)^3}$$

$$= 0.38\ KSF \pm 0.25\ KSF$$

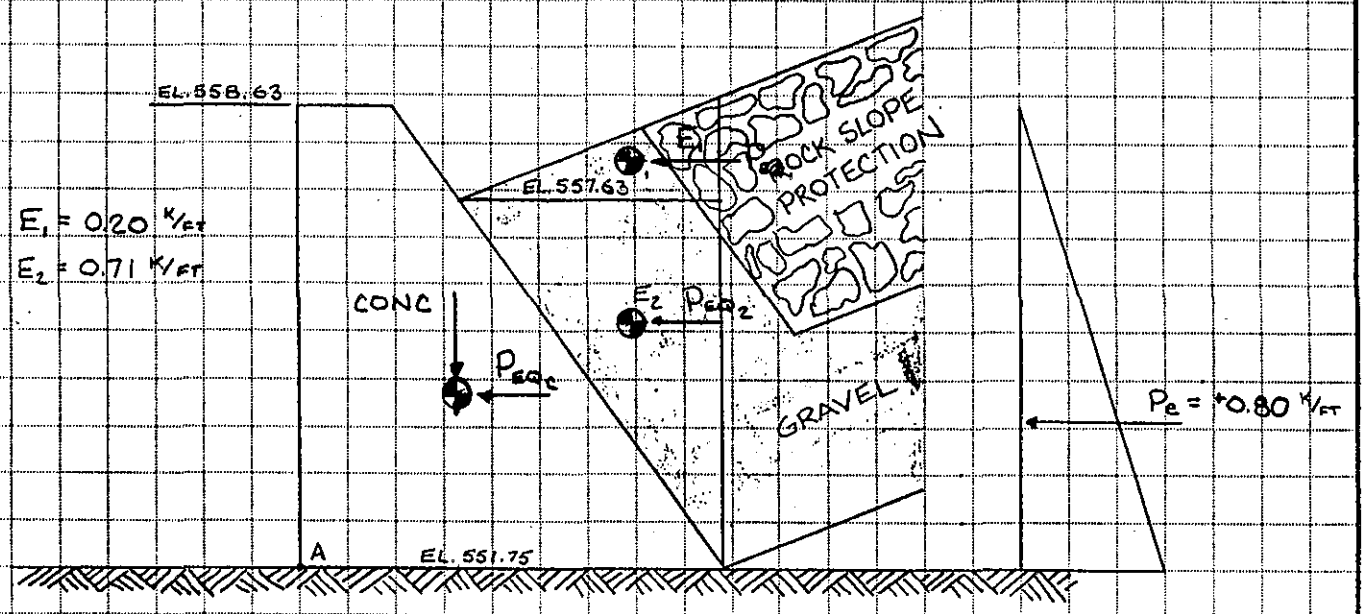
$f_{MAX} = 0.63$ KSF OK ($f_{ALLOW} = 40$ KSF)

$f_{min} = 0.13$ KSF

SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY) (CONT)

SECTION ②

LOADING CONDITION CASE III - EARTHQUAKE LOADING



$P_{EQ_C} = 0.10(2.35) = 0.24$ K/FT

$P_{EQ_1} = 0.10(0.20) = 0.02$ K/FT

$P_{EQ_2} = 0.10(0.71) = 0.07$ K/FT

ITEM	FORCE	ARM	MOMENT
CONC	1.98 V		3.05
E_1	0.20 V	3.51	0.70
E_2	0.71 V	3.51	2.49
P_e	-0.80 H	3.68	-2.90
P_{EQ_C}	-0.24 H	1.88	-0.45
P_{EQ_1}	-0.02 H	6.24	-0.12
P_{EQ_2}	-0.07 H	1.96	-0.14
	$\Sigma V = 2.89$ K/FT		$\Sigma M = 2.63$ FT-K/FT
	$\Sigma H = -1.13$ K/FT		

SOUTH ABUTMENT RETAINING WALL (AT STAIRWAY) (CONT)

SECTION 2

LOADING CONDITION CASE III (CONT)

CHECK OVERTURNING

$\Sigma M / \Sigma V = 2.63 / 2.89 = 0.91'$

$0 < 0.91' < 4.42'$
RESULTANT WITHIN BASE OK

CHECK SLIDING

$$FS = \frac{(80\ PSI)(4.42)(144\ IN^2/FT^2) + (2890\ \#/FT)\ TAN\ 26.56°}{1130\ \#/FT}$$

$FS = 46 > 1.5$ OK

CHECK BEARING PRESSURE

$f_{max} = \frac{2V}{3e}$ $e = 0.91'$

$f_{max} = \frac{2(2.89K)}{3(0.91)} = 2.12$ ksf ($f_{allow} = 40$ ksf)

OK

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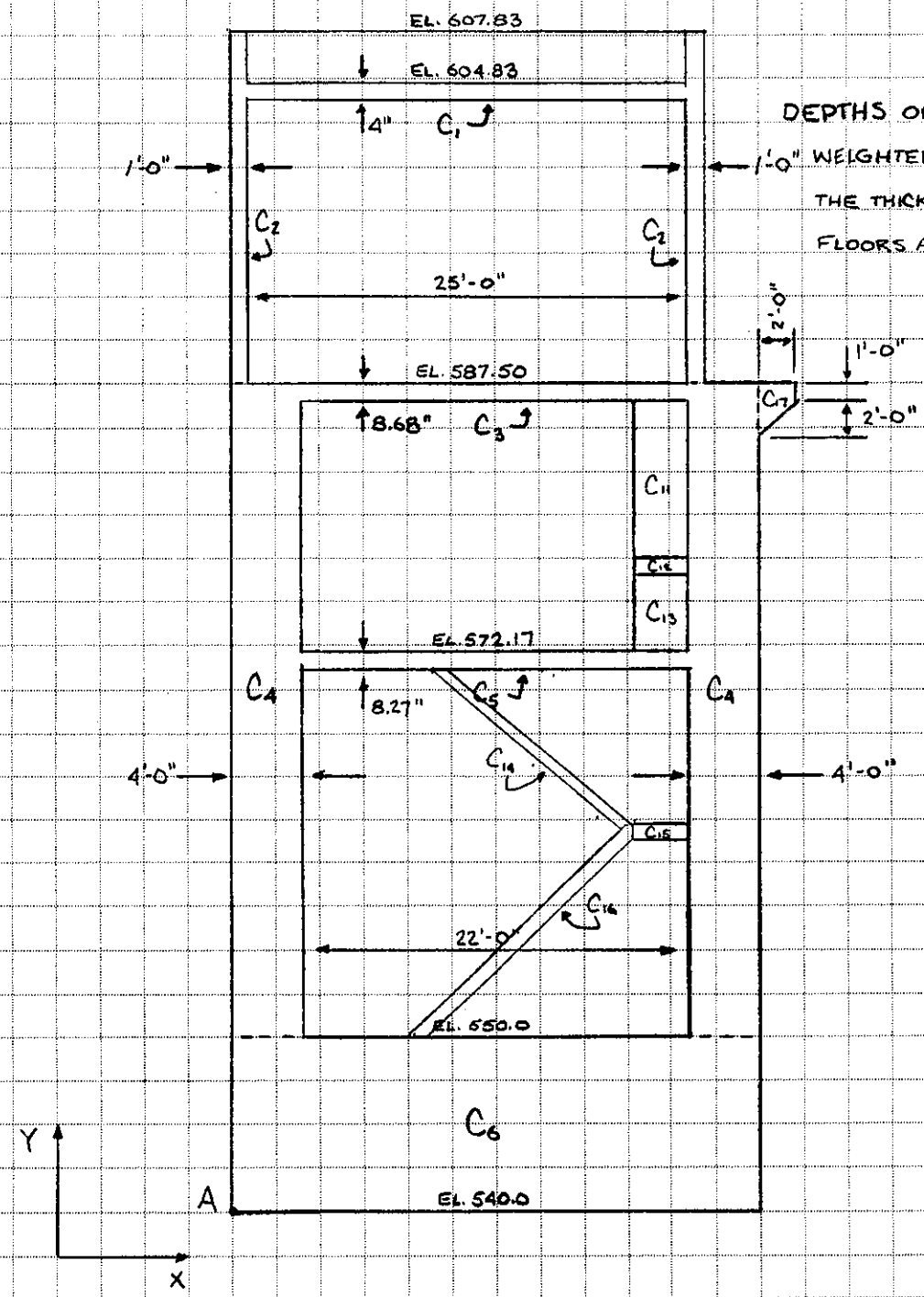
JOB WESTVILLE DAM STABILITY ANALYSIS
SHEET NO. 108 OF
CALCULATED BY JMS DATE 11/6/87
CHECKED BY LFV DATE 1/27/88
SCALE

CONTROL HOUSE STABILITY



DEPTHS OF SLABS A WEIGHTED AVERAGE OF THE THICKNESS OF THE FLOORS AND THE DIAPHRAGMS

SECTION LOOKING E-W

PRODUCT 204-1 NEBS Inc., Groton, Mass. 01471.

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SHEET NO. 109 OF
CALCULATED BY: JMS DATE: 11/6/87
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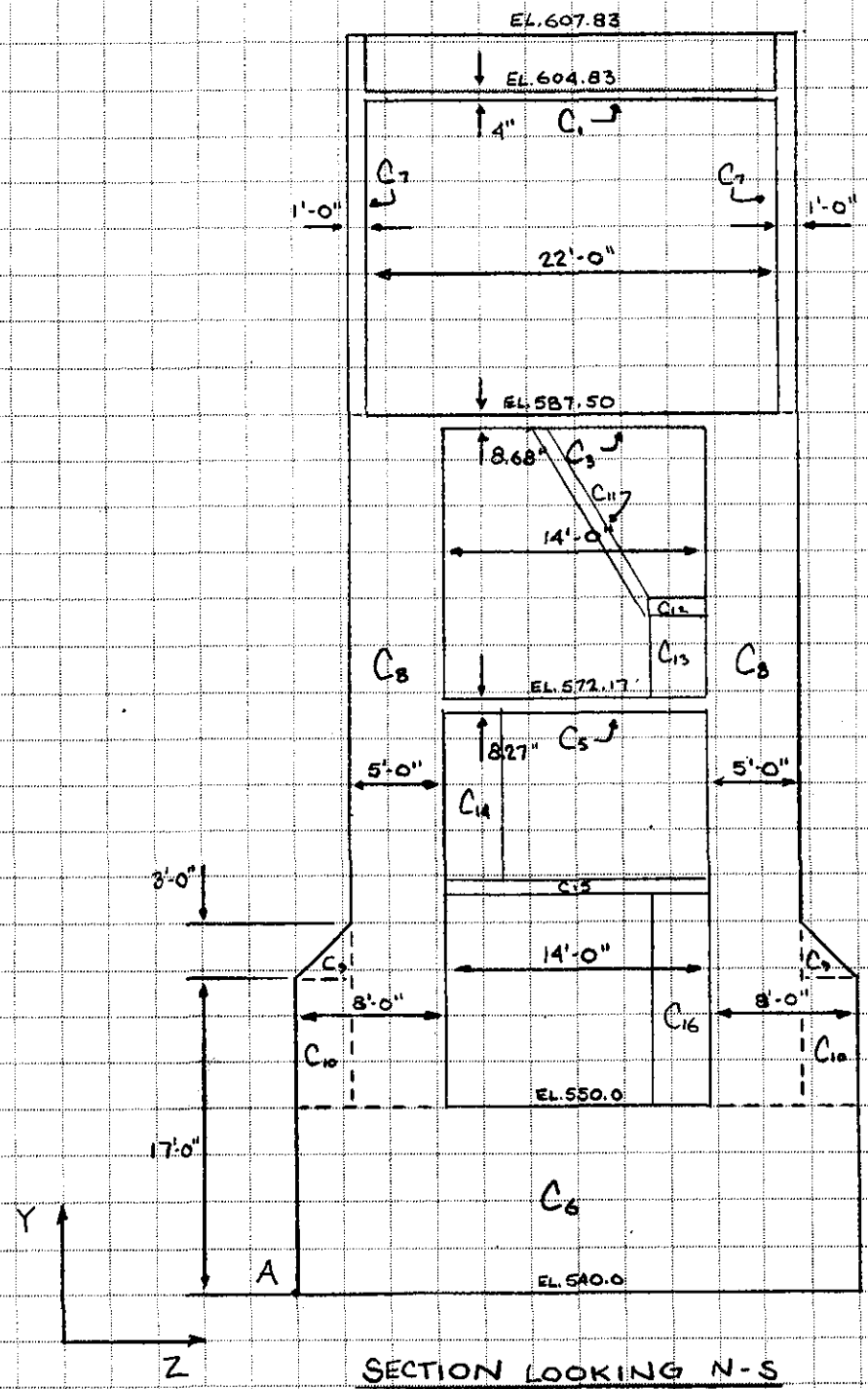
SCALE

CONTROL HOUSE STABILITY (CONT)



SECTION LOOKING N-S

PRODUCT 204-1 NEBS Inc., Groton, Mass. 01471.

JOB Westville Dam Stability Analysis OF

SHEET NO. 110

CALCULATED BY JMS DATE 11/6/87

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SCALE

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CONTROL HOUSE STABILITY (CONT)

ITEM	VOLUME	WEIGHT	ALONG X-X AXIS		ALONG Y-Y AXIS		ALONG Z-Z AXIS	
	FT^3	K	ARM	M_{x-x}	ARM	M_{y-y}	ARM	M_{z-z}
C_1	(0.33)(25)(22) = 183.33	27.50	13.50	371.25	64.67	1778.33	15.00	412.50
C_2	2(1)(20.33)(24) = 976.00	146.40	13.50	1976.40	57.67	8442.40	15.00	2196.00
C_3	(0.72)(22)(14) = 222.79	33.42	15.00	501.27	47.14	1575.28	15.00	501.27
C_4	2(4)(37.5)(24) = 7200.00	1080.00	15.00	16200.00	28.75	31050.00	15.00	16200.00
C_5	(0.69)(22)(14) = 212.26	31.84	15.00	477.59	31.83	1013.31	15.00	477.59
C_6	(10)(30)(30) = 9000.00	1350.00	15.00	20250.00	5.00	6750.00	15.00	20250.00
C_7	2(1)(20.33)(25.00) = 1016.67	152.50	13.50	2058.75	57.67	8794.17	15.00	2287.50
C_8	2(5)(37.5)(22) = 8250.00	1237.50	15.00	18562.50	28.75	35578.13	15.00	18562.50
C_9	(3)(3)(30) = 270.00	40.50	15.00	607.50	18.00	729.00	15.00	607.50
C_{10}	2(7)(3)(30) = 1260.00	189.00	15.00	2835.00	13.50	2551.50	15.00	2835.00
C_{11}	(3)(15)(1) = 45.00	6.75	24.50	165.38	42.50	286.88	10.73	72.46
C_{12}	(3.03)(3.03)(1) = 9.19	1.38	24.48	33.75	37.00	51.00	20.48	28.23
C_{13}	(3)(8)(1) = 24.00	3.60	20.34	73.22	34.84	125.41	20.50	73.80
C_{14}	(3)(1)(15) = 45.00	6.75	17.73	119.71	27.17	183.40	9.50	64.13
C_{15}	(3)(1)(14) = 42.00	6.30	24.50	154.35	21.67	136.52	15.00	94.50
C_{16}	(3)(1)(18) = 54.00	8.10	16.63	134.66	16.09	130.29	20.50	166.05
C_{17}	$[(2)(1)+\frac{1}{2}(2)(2)]24 = 96.00$	14.40	30.83	444.00	46.42	668.40	15.00	216.00
OPERATING ROOM: HATCH	(7)(3)(0.58) = 12.25	-1.84	5.50	-10.11	47.21	-86.75	15.00	-27.56
OPERATING ROOM: STAIR WELL	(10)(3)(0.58) = 17.50	-2.63	24.50	-64.31	47.21	-123.92	13.50	-35.44
OPERATING ROOM: WINDOW	(3.75)(10.17)(1) = 38.13	-5.72	13.50	-77.20	54.50	-311.67	3.50	-20.02
OPERATING ROOM: WINDOW	38.13	-5.72	26.50	-151.55	54.50	-311.67	15.00	-81.28
OPERATING ROOM: WINDOW	38.13	-5.72	17.50	-100.08	54.50	-311.67	26.50	-151.55
OPERATING ROOM: DOOR	(3)(7)(1) = 21.00	-3.15	26.50	-83.48	51.08	-160.91	3.00	-9.45
OPERATING ROOM: DOOR	(5.67)(8.33)(1) = 47.22	-7.08	0.50	-3.54	51.67	-365.97	15.00	-106.25

PRODUCT 204-1 NEBS Inc. Groton, Mass. 01471.

JOB WESTVILLE DAM STABILITY ANALYSIS

SHEET NO. 111 OF

CALCULATED BY JMS DATE 11/9/87

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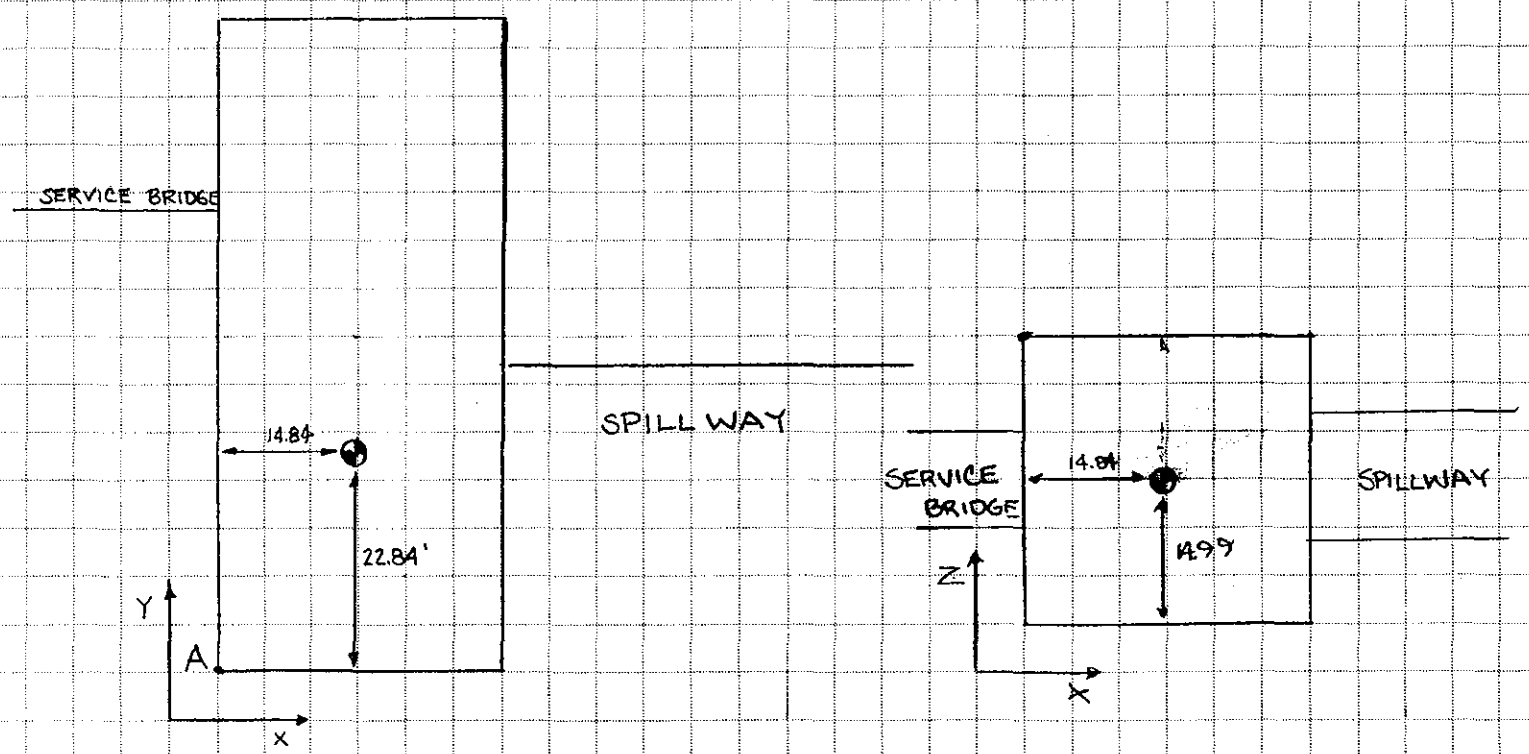
CONTROL HOUSE STABILITY (CONT)

ITEM	VOLUME	WEIGHT	ALONG X-X AXIS		ALONG Y-Y AXIS		ALONG Z-Z AXIS	
	FT^3	K	ARM	MOMENT	ARM	MOMENT	ARM	MOMENT
572.17 HATCH	12.25	-1.84	5.50	-10.11	31.88	-58.58	15.00	-27.56
572.17 STAIRWELL	17.50	-2.63	17.50	-45.94	31.88	-83.69	6.5	-17.06
GALLERY	(6)(7)(4) = 168.00	-25.20	28.00	-705.60	13.50	-340.20	15.00	-378.00
VENT	$(3.14)(1)^2(33.5) = 105.24$	-15.78	28.00	-442.02	26.75	-422.29	21.67	-342.04
VENT	$(3.14)(0.5)^2(33.5) = 26.31$	-3.95	28.00	-110.51	26.75	-105.57	17.17	-67.75
		4254.68K	14.84 FT	63160.88 FT-K	22.84 FT	97161.13 FT-K	14.99 FT	63781.07 FT-K



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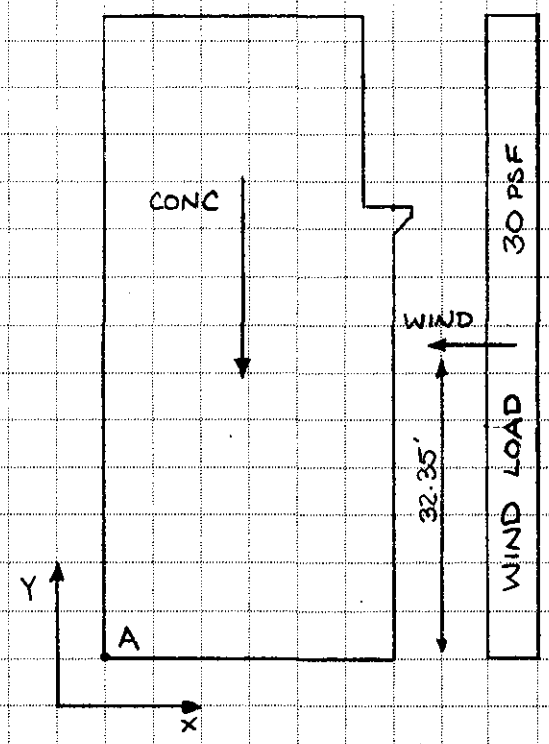
CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE Ia - CONSTRUCTION CONDITION

WIND NORTH - SOUTH



WIND $= 0.03[(30)(17) + (24)(50.83) + \frac{1}{2}(6)(3)]$

$= 52.17^K$

SEE SH. 109
AREA OF C_g

ITEM	FORCE (K)	ARM (FT)	MOMENT (FT-K)
CONC	4254.68 ↓		63160.88
WIND	-52.17 ←	32.35	-1687.7
	$\Sigma V = 4254.68^K$		61473.18 FT-K
	$\Sigma H = -52.17^K$		

CHECK OVERTURNING

$\Sigma M / \Sigma V = 61473.18 / 4254.68 = 14.4'$

$10 < 14.4 < 20$ OK RESULTANT WITHIN MIDDLE THIRD

CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE Ia (CONT)

CHECK SLIDING

$$FS = \frac{(80\ PSI)(30\ FT)^2(144\ IN^2/FT^2) + (4254680\ \#)\ TAN\ 26.56^\circ}{52170\ \#}$$

$FS = 239.5 > 2$ OK

CHECK BEARING PRESSURE

$$f = \frac{4254.68^K}{(30')^2} \pm \frac{(4254.68^K)(15.0' - 14.4')(15.0')}{\frac{1}{12}(30)^4}$$

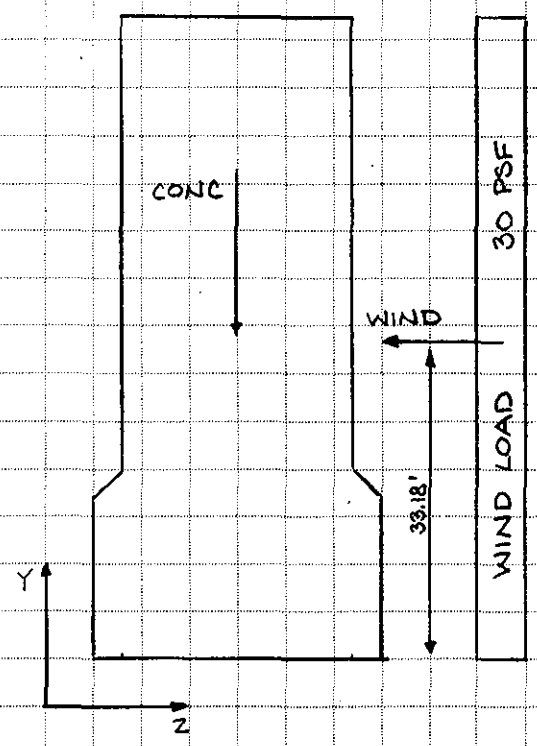
$$= 4.73\ KSF \pm 0.57\ KSF$$

$f_{MAX} = 5.30\ KSF$ OK ($f_{ALLOW} = 40\ KSF$)

CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE Ib - CONSTRUCTION CONDITION

WIND EAST-WEST



WIND = 0.03[(30)(47.5) + (27)(20.33)]
= 59.22^K

ITEM	FORCE (K)	ARM (FT)	MOMENT (FT-K)
CONC	4254.68 ↓		63781.07
WIND	-59.22 ←	33.18	-1964.92
	$\Sigma V = 4254.68^K$		$\Sigma M = 61816.15$ FT-K
	$\Sigma H = -59.22^K$		

CHECK OVERTURNING

$\Sigma M / \Sigma V = 61816.15 / 4254.68 = 14.5'$

$10 < 14.5 < 20$ (OK) RESULTANT WITHIN MIDDLE THIRD

CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE Ib (CONT)

CHECK SLIDING

$$FS = \frac{(80\ PSI)(30\ FT)^2(144\ IN^2/FT^2) + (4254680\#)\ TAN\ 26.56^\circ}{59220\#}$$

$FS = 211 > 2$ OK

CHECK BEARING PRESSURE

$$f = \frac{4254.68^K}{(30')^2} \pm \frac{(4254.68^K)(15.0' - 14.5')(15.0')}{\frac{1}{12}(30')^4}$$

$= 4.73\ KSF \pm 0.47\ KSF$

$f_{MAX} = 5.20\ KSF$ OK ($f_{ALLOW} = 40\ KSF$)

WIND IN BOTH DIRECTIONS

CHECK BEARING PRESSURE

$$f_{MAX} = \left[(5.30\ KSF)^2 + (5.20\ KSF)^2\right]^{\frac{1}{2}} = 7.42\ KSF$$ OK

($f_{ALLOW} = 40\ KSF$)

JOB Westville Dam Stability Analysis

SHEET NO. 110 OF

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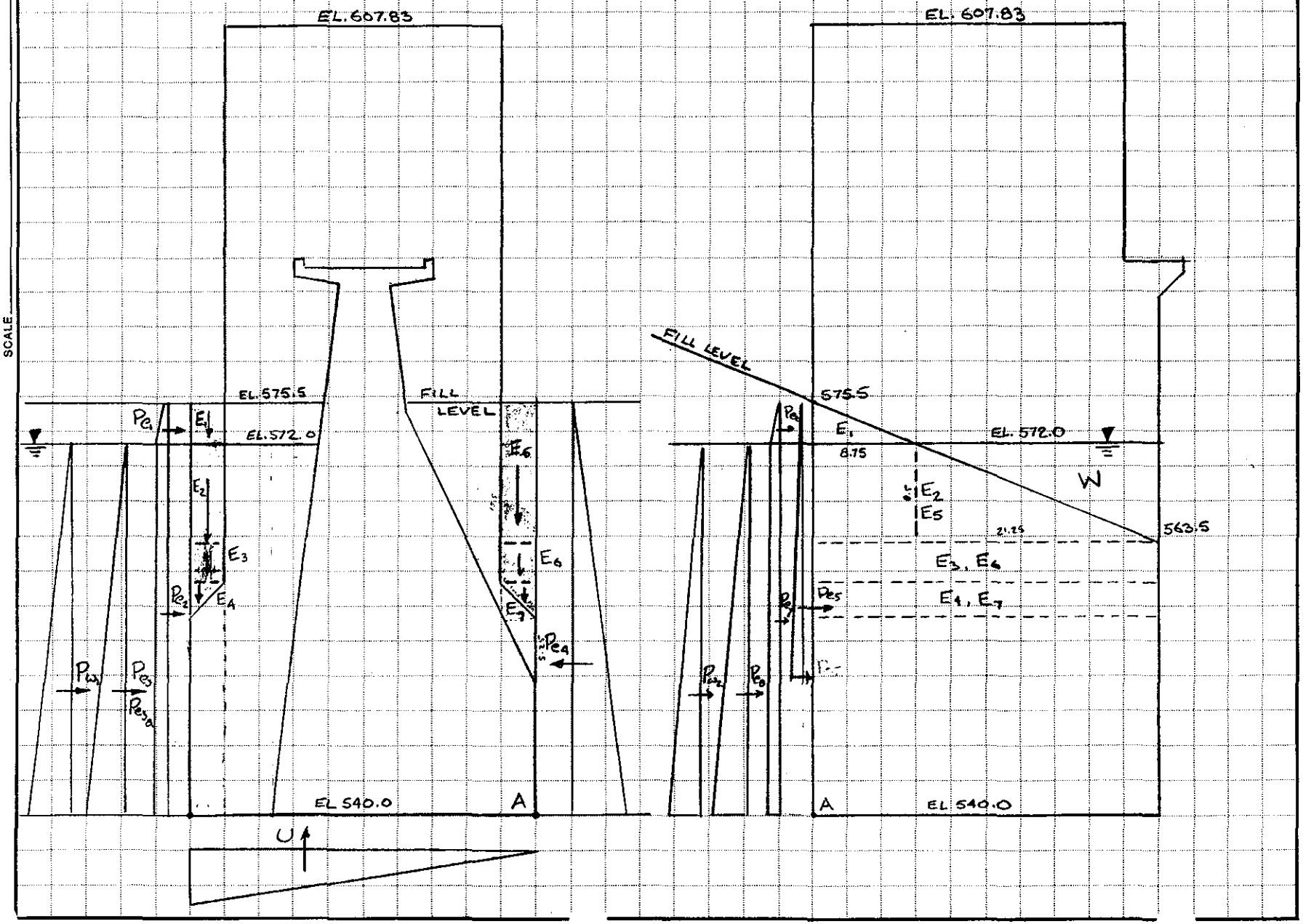
CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE II - NORMAL LOADING CONDITION



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CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE II (CONT)

$E_1 = (0.135)\,\frac{1}{2}(8.75)(3.5)(3) = 6.20^K$

$E_2 = (0.141)\left[(8.75)(8.5)(3) + \frac{1}{2}(8.5)(21.25)(3)\right] = 69.66^K$

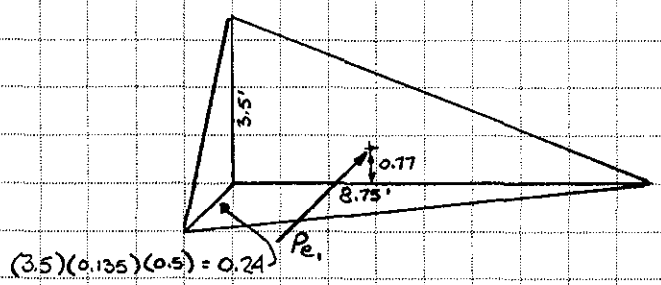
$E_3 = (0.141)(3.5)(30)(3) = 44.42^K$

$E_4 = (0.141)\,\frac{1}{2}(3)(3)(30) = 19.04^K$

$E_5 = (0.135)\,\frac{1}{2}(30)(12)(3) = 72.90^K$

$E_6 = (0.135)(3.5)(30)(3) = 42.53^K$

$E_7 = (0.135)\,\frac{1}{2}(3)(3)(30) = 18.23^K$

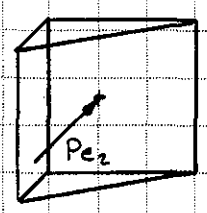


$P_{e_1} = \frac{1}{3}Ah$ (VOLUME OF PYRAMID)

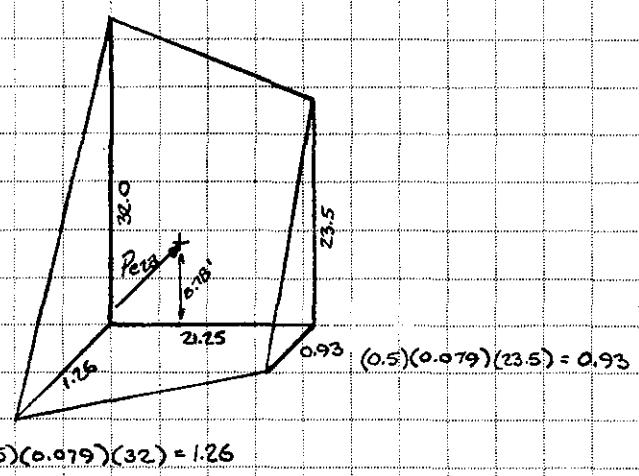
$= \frac{1}{3}\left(\frac{1}{2}(0.24)(3.5)(8.75)\right)$

$= 1.22^K$

$P_{e_2} = \frac{1}{2}(0.24)(32)(8.75) = 33.60^K$



$P_{e_3} = \frac{1}{2}(0.5)(32)^2(0.079)(8.75) = 176.96^K$



$P_{e_{3a}} = \int A\,dL \qquad A = \frac{1}{2}(0.5)(0.079)(H)^2$

$H = 0.4L + 23.5$

$A = 0.00316L^2 + 0.3713L + 10.9069375$

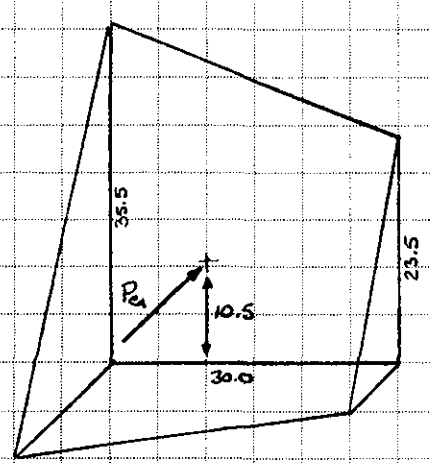
$P_{e_{3a}} = \int_0^{21.25}(0.00316L^2 + 0.3713L + 10.9069375)\,dL$

$= \left/_0^{21.25} \frac{0.00316L^3}{3} + \frac{0.3713L^2}{2} + 10.9069375L\right.$

$= 325.78^K$

CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE II (CONT)



$P_{e_4} = \int A\,dL$ $\quad A = \frac{1}{2}(0.5)(0.135)(H)^2$

$H = 0.4L + 23.5$

$A = 0.0054\,L^2 + 0.6345\,L + 18.6384375$

$$P_{e_4} = \int_0^{30} (0.0054\,L^2 + 0.6345\,L + 18.6384375)\,dL$$

$$= \int_0^{30} 0.0054\,L^3/3 + 0.6345\,L^2/2 + 18.6384375\,L$$

$$= 893.28^K$$

$P_{e_5} = \frac{1}{2}(0.5)(0.135)(23.75)^2(\overset{\text{APPROX}}{3.77}) = 71.71^K$

$P_{e_6} = \frac{1}{2}(0.5)(0.135)(3.5)^2\left(\frac{8.5 + 8.06}{2}\right) = 3.42^K$

$P_{e_7} = (0.5)(0.135)(3.5)(249.5) = 58.94^K$

$P_{e_8} = \frac{1}{2}(0.5)(0.079)(32)^2(\overset{\text{APPROX}}{7.80}) = 157.68^K$

$P_{\omega_1} = \frac{1}{2}(0.0625)(32)^2(30) = 960^K$

$P_{\omega_2} = \frac{1}{2}(0.0625)(32)^2(\overset{\text{APPROX}}{7.80}) = 249.50^K$

$U = \frac{1}{2}(0.0625)(32)(30)(30) = 900^K$

$W = \frac{1}{2}(8.5)(21.25)(3)(0.0625) = 16.93^K$

JOB Westville Dam Stability Analysis

SHEET NO. 119 OF

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CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE II (CONT)

	ITEM	FORCE K	ABOUT X-X AXIS ARM	ABOUT X-X AXIS MOMENT	ABOUT Z-Z AXIS ARM	ABOUT Z-Z AXIS MOMENT
	CONC	4254.68		63160.88		63781.07
HORIZONTAL	E_1	6.20	28.50	176.70	2.92	18.10
HORIZONTAL	E_2	69.66	28.50	1985.31	10.66	742.58
HORIZONTAL	E_3	44.42	28.50	1265.97	15.00	666.30
HORIZONTAL	E_4	19.04	29.00	552.16	15.00	285.60
HORIZONTAL	E_5	72.90	1.50	109.35	10.00	729.00
HORIZONTAL	E_6	42.53	1.50	63.80	15.00	637.95
HORIZONTAL	E_7	18.23	1.00	18.23	15.00	273.45
HORIZONTAL	W	16.93	28.50	482.51	22.92	387.98
HORIZONTAL	U	-900.00	20.00	-18000.00	15.00	-13500.00
VERTICAL	P_{e_1}	-1.22	32.78	-39.99		
VERTICAL	P_{e_2}	-33.60	16.00	-537.60		
VERTICAL	P_{e_3}	-176.96	10.67	-1887.57		
VERTICAL	$P_{e_{3a}}$	-325.78	8.78	-2860.35		
VERTICAL	P_{e_4}	893.28	10.50	9379.44		
VERTICAL	P_{e_5}	71.71			19.67	1410.30
VERTICAL	P_{e_6}	3.42			33.17	113.43
VERTICAL	P_{e_7}	58.94			16.00	943.04
VERTICAL	P_{e_8}	157.68			10.67	1681.92
VERTICAL	P_{w_1}	-960.00	10.67	-10240.00		
VERTICAL	P_{w_2}	249.50			10.67	2661.33
		$\Sigma V = 3644.59^K$		$\Sigma M_x = 43628.84$		$\Sigma M_y = 60832.05^{FT-K}$
		$\Sigma H_z = -604.28$		$\Sigma H_x = 541.25^K$		

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CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE II (CONT)

CHECK OVERTURNING

EAST-WEST

$\Sigma M / \Sigma V = 43628.8 / 3644.59 = 11.97$

$10' < 11.97' < 20'$ OK RESULTANT WITHIN MIDDLE THIRD

NORTH-SOUTH

$\Sigma M / \Sigma V = 60832.05 / 3644.59 = 16.7'$

$10' < 16.7' < 20'$ OK RESULTANT WITHIN MIDDLE THIRD

CHECK SLIDING

EAST-WEST (WORST CASE)

$$FS = \frac{(80\ PSI)(30\ FT)^2(144\ IN^2/FT^2) + (3644590\#)\tan 26.56^\circ}{604280\#}$$

$= 20.17 > 2$ OK

CHECK BEARING PRESSURE

$$f = \frac{3644.59^K}{(30\ FT)^2} \pm \frac{(3644.59^K)(11.97'-15.0')(15.0')}{\frac{1}{12}(30')^4} \pm \frac{(3644.59^K)(16.7'-15.0')(15.0')}{\frac{1}{12}(30')^4}$$

$f = 4.05\ KSF \pm 2.45\ KSF \pm 1.38\ KSF$

$f_{MAX} = 7.88\ KSF$ OK ($f_{ALLOW} = 40\ KSF$)

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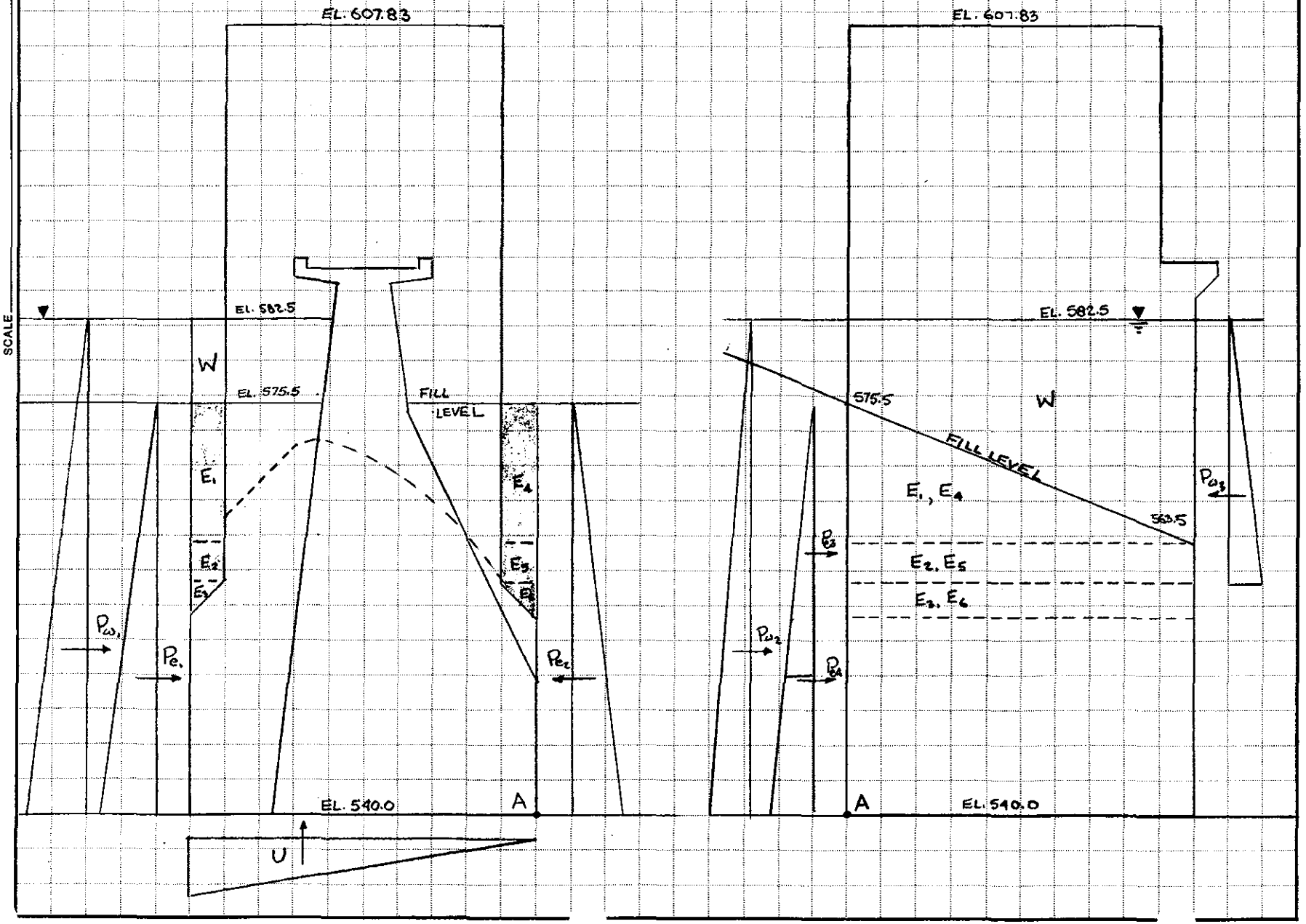
CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE III - FLOOD CONDITION



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CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE III (CONT)

$E_1 = (0.141)\frac{1}{2}(30)(12)(3) = 76.14^K$

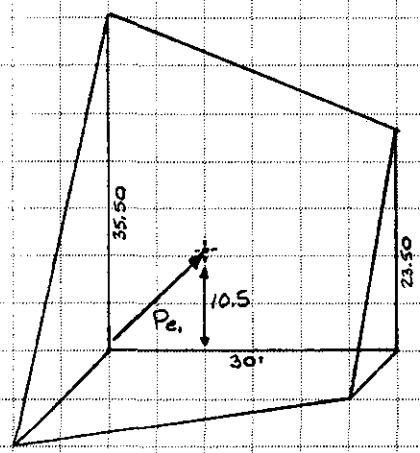
$E_2 = (0.141)(3.5)(30)(3) = 44.42^K$

$E_3 = (0.141)\frac{1}{2}(3)(3)(30) = 19.03^K$

$E_4 = (0.135)\frac{1}{2}(30)(12)(3) = 72.90^K$

$E_5 = (0.135)(3.5)(30)(3) = 42.53^K$

$E_6 = (0.135)\frac{1}{2}(3)(3)(30) = 18.23^K$



$P_{e_1} = \int_0^{30} A\,dL$ $\quad A = \frac{1}{2}(0.5)(0.079)(H)^2$

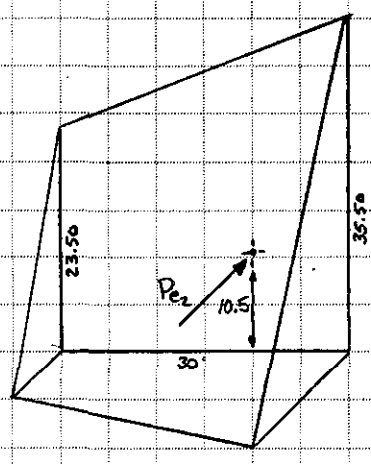
$H = 0.4L + 23.5$

$A = 0.00316L^2 + 0.3713L + 10.9069375$

$P_{e_1} = \int_0^{30} (0.00316L^2 + 0.3713L + 10.9069375)\,dL$

$= \int_0^{30} 0.00316\,L^3/3 + 0.3713\,L^2/2 + 10.9069375\,L$

$= 522.73^K$



$A = \frac{1}{2}(0.5)(0.135)(H)^2$

$A = 0.0054L^2 + 0.6345L + 18.6384375$

$P_{e_2} = \int_0^{30} (0.0054L^2 + 0.6345L + 18.6384375)\,dL$

$= \int_0^{30} 0.0054\,L^3/3 + 0.6345\,L^2/2 + 18.6384375\,L$

$= 893.28^K$

CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE III (CONT)

$P_{e3} = \frac{1}{2}(0.5)(0.135)(23.75)^2(\overset{\text{APPROX}}{3.77}) = 71.17^K$

$P_{e4} = \frac{1}{2}(0.5)(0.079)(35.5)^2(\overset{\text{APPROX}}{7.80}) = 194.14^K$

$P_{w_1} = \frac{1}{2}(0.0625)(42.5)^2(30) = 1693.36^K$

$P_{w_2} = \frac{1}{2}(0.0625)(42.5)^2(\overset{\text{APPROX}}{7.80}) = 440.27^K$

$P_{w_3} = \frac{1}{2}(0.0625)(16.87)^2(9) = 80.04^K$

$U = \frac{1}{2}(0.0625)(42.5)(30)(30) = 1195.31^K$

$W = (0.0625)\left(\frac{7+19}{2}\right)(30)(3) = 73.13^K$

CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE III (CONT)

ITEM	FORCE	ABOUT X-X AXIS		Z-Z AXIS	
	K	ARM	MOMENT	ARM	MOMENT
CONC	4254.68		63160.88		63781.07
E_1	76.14	28.5	2169.99	10.0	761.04
E_2	44.42	28.5	1265.97	15.0	666.30
E_3	19.03	29.0	551.87	15.0	285.45
E_4	72.90	1.5	109.35	10.0	729.00
E_5	42.53	1.5	63.80	15.0	637.95
E_6	18.23	1.0	18.23	15.0	273.45
W	73.13	28.5	2084.21	17.3	1265.63
U	-1195.31	10.0	-11953.10	15.0	-17929.65
P_{e_1}	-522.73	10.5	-5488.67		
P_{e_2}	893.28	10.5	9379.44		
P_{ω_1}	-1693.36	14.2	-23989.27		
P_{e_3}	71.17			19.67	1399.7
P_{e_4}	194.14			11.8	2297.32
P_{ω_2}	440.27			14.2	6237.16
P_{ω_3}	-80.04			31.25	-2501.52
	$\Sigma V = 3405.75^K$		$\Sigma M_x = 37372.7^{FT\text{-}K}$		$\Sigma M_y = 57902.9^{FT\text{-}K}$
	$\Sigma H_z = -1322.81^K$				
	$\Sigma H_x = 625.54^K$				

CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE III (CONT)

CHECK OVERTURNING

EAST - WEST

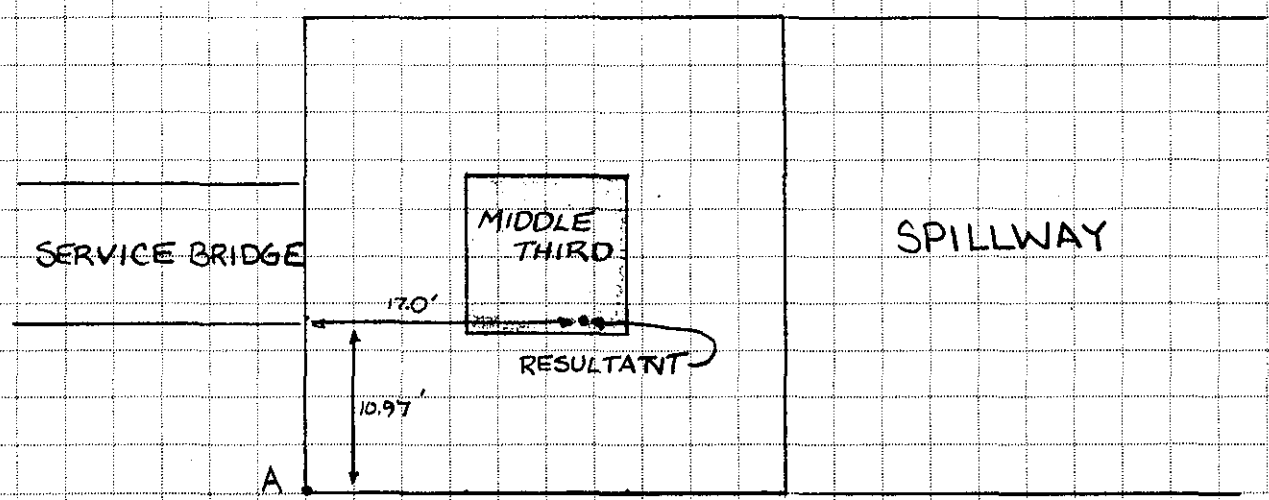
$\Sigma M_x / \Sigma V = 37372.7 / 3405.75 = 10.9$

$10' < 10.97' < 20'$ (OK) RESULTANT WITHIN MIDDLE THIRD

NORTH - SOUTH

$\Sigma M_y / \Sigma V = 57902.9 / 3405.75 = 17.0$

$10' < 17.0' < 20'$ (OK) RESULTANT WITHIN MIDDLE THIRD



CHECK SLIDING

EAST-WEST (WORST CASE)

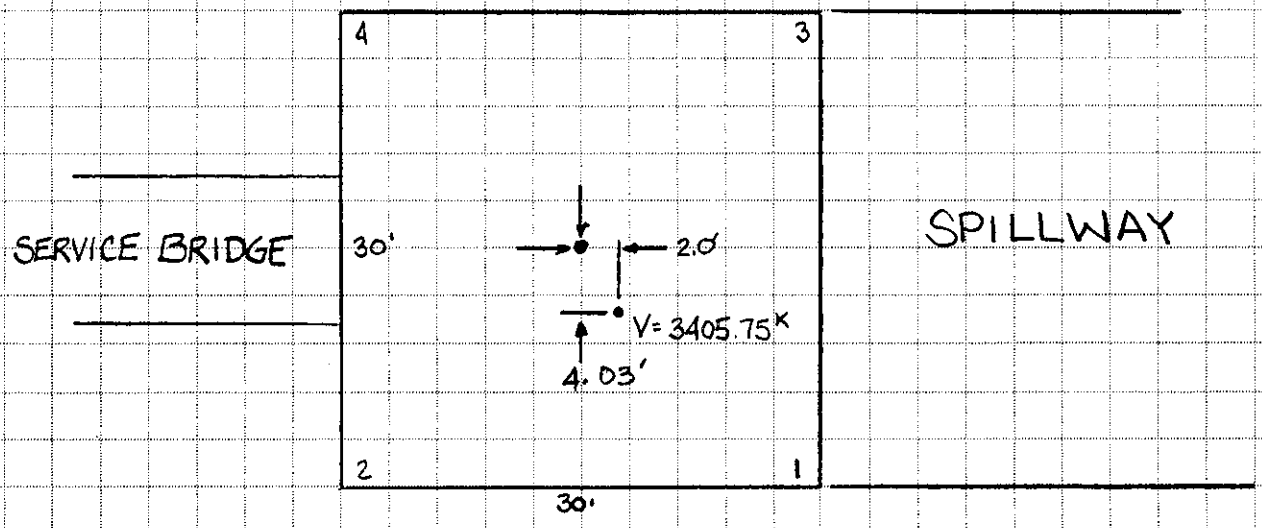
$$FS = \frac{(80\ PSI)(30\ FT)^2(144\ IN^2/FT^2) + (3405750\#)\ TAN\ 26.56^\circ}{1322810\#}$$

$FS = 9.1 > 2$ (OK)

CONTROL HOUSE STABILITY (CONT.)

LOADING CONDITION CASE III (CONT)

CHECK BEARING PRESSURE



$$f = \frac{3405.75^K}{(30')^2} \pm \frac{(3405.75^K)(4.03')(15.0')}{\frac{1}{12}(30')^4} \pm \frac{(3405.75^K)(2.0')(15.00)}{\frac{1}{12}(30')^4}$$

$$= 3.78 \text{ KSF} \pm 3.05 \text{ KSF} \pm 1.51 \text{ KSF}$$

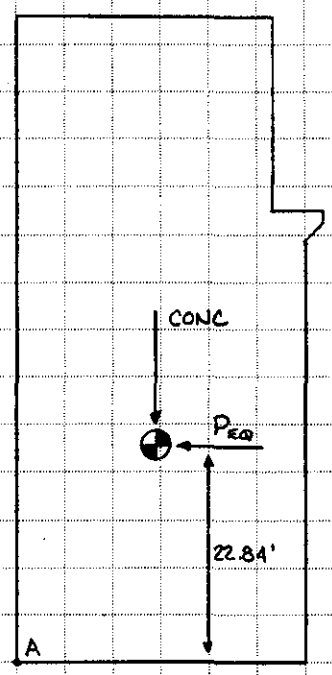
$$f_1 = 8.34 \text{ KSF}$$

OK (f_{ALLOW} = 40 KSF)

CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE IV - CONSTRUCTION CONDITION W/ EARTHQUAKE

$P_{EQ} = (0.10)(4254.68) = 425.47^{K}$



ITEM	FORCE (K)	ARM (FT)	MOMENT (FT-K)
CONC	4254.68 ↓		63160.88
P_{EQ}	-425.47 ←	22.84	-9717.73
	$\Sigma V = 4254.68^{K}$		53443.15 FT-K
	$\Sigma H = -425.47$		

CHECK OVERTURNING

$\Sigma M / \Sigma V = 53443.15 / 4254.68 = 12.56'$

$10' < 12.56' < 20'$ OK RESULTANT WITHIN MIDDLE THIRD

CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE IV (CONT)

CHECK SLIDING

$$FS = \frac{(80\ PSI)(30\ FT)^2(144\ IN^2/FT^2) + (4254680\#)\ TAN\ 26.56^\circ}{425468\#}$$

$FS = 29.4 > 2$ OK

CHECK BEARING PRESSURE

$$f = \frac{4254.68^K}{(30')^2} \pm \frac{(4254.68^K)(15.0 - 12.50)(15.0)}{\frac{1}{12}(30')^4}$$

$f = 4.73\ KSF \pm 2.31\ KSF$

$f_{MAX} = 7.04\ KSF$ OK ($f_{ALLOW} = 40\ KSF$)

CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE V a - NORMAL OPERATING CONDITION WITH EARTHQUAKE IN EAST - WEST DIRECTION

FORCE DUE TO STRUCTURE

$$P_{EQ_1} = (0.10)(4254.68 + 6.20 + 69.66 + 44.42 + 19.04 + 72.90 + 42.53 + 18.23 + 16.93)$$

$$= 454.46^K \text{ ACTING AT } 22.84' \text{ ABOVE BASE}$$

FORCE DUE TO RESERVOIR WATER

$$C_e = \frac{51}{\sqrt{1 - 0.72\left(\frac{h}{1000 t_e}\right)^2}}$$

$$= \frac{51}{\sqrt{1 - 0.72\left(\frac{67.83}{1000(1')}\right)^2}}$$

$$= 51.08$$

$$P_{EQ_2} = \frac{2}{3} C_e \alpha Y \sqrt{hY}\ L$$

$$= \frac{2}{3}(51.08)(0.10)(8.5)[(67.83)(8.5)]^{\frac{1}{2}}(21.25)/1000$$

$$= 14.77^K \text{ ACTING AT } [0.4(Y) + 23.5] = 26.9' \text{ FROM BASE}$$

CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE V a (CONT)
WITH EARTHQUAKE IN EAST-WEST DIRECTION

ITEM	FORCE (K)	ARM (FT)	MOMENT (FT-K)
CASE II	3644.59 ↓		43628.34
	z -604.28		
P_{EQ_1}	z -454.46	22.84	-10379.87
P_{EQ_2}	z - 14.77	26.90	-397.31
	$\Sigma V =$ 3644.59 K		$\Sigma M_x =$ 32851.16 FT-K
	$\Sigma H =$ -1073.51 K		

CHECK OVERTURNING

$$\Sigma M_x / \Sigma V = 32851.16 / 3644.59 = 9.01'$$

$0' < 9.01' < 30'$ OK RESULTANT WITHIN BASE

CHECK SLIDING

$$FS = \frac{(80\ PSI)(30\ FT)^2(144\ IN^2/FT^2) + (3644590\#)\ TAN\ 26.56^\circ}{1073510\ \#}$$

$FS = 11.4 > 2$ OK

CHECK BEARING PRESSURE

REFERENCE: LOADING CASE II NORTH-SOUTH DIRECTION

$$* \quad f = \frac{3644.59^K}{(30')^2} \pm \frac{(3644.59^K)(9.01' - 15.0')(15.0')}{\frac{1}{12}(30')^4} \pm 1.38\ KSF$$

$$= 405\ KSF \pm 4.85\ KSF \pm 1.38\ KSF$$

$f_{MAX} = 10.28$ KSF OK ($f_{ALLOW} = 40$ KSF)

* This equation is used in lieu of $f_{max} = \frac{2V}{3e}$ as an approximation so that bi-axial bending can be computed. The resulting f is significantly below the $f_{allow} = 40$ KSF. ✓ OK

CONTROL HOUSE STABILITY (CONT)

LOADING CONDITION CASE IV b - NORMAL OPERATING CONDITION WITH EARTHQUAKE IN NORTH-SOUTH DIRECTION

ITEM	FORCE (K)	ARM (FT)	MOMENT (FT-K)
CASE II	3644.59		60832.05
P_{EQ}	541.25 + 454.46	22.84	10379.87
	$\Sigma V = 3644.59^K$		$\Sigma M = 71211.92^{FT-K}$
	$\Sigma H_x = 995.71^K$		

CHECK OVERTURNING

$$\Sigma M / \Sigma V = 71211.92 / 3644.59 = 19.54'$$

$10' < 19.54' < 20'$ OK RESULTANT WITHIN MIDDLE THIRD

CHECK SLIDING

$$FS = \frac{(80\ PSI)(30')^2(144\ IN^2/FT^2) + (3644590^{\#})\ TAN\ 26.56^\circ}{995710^{\#}}$$

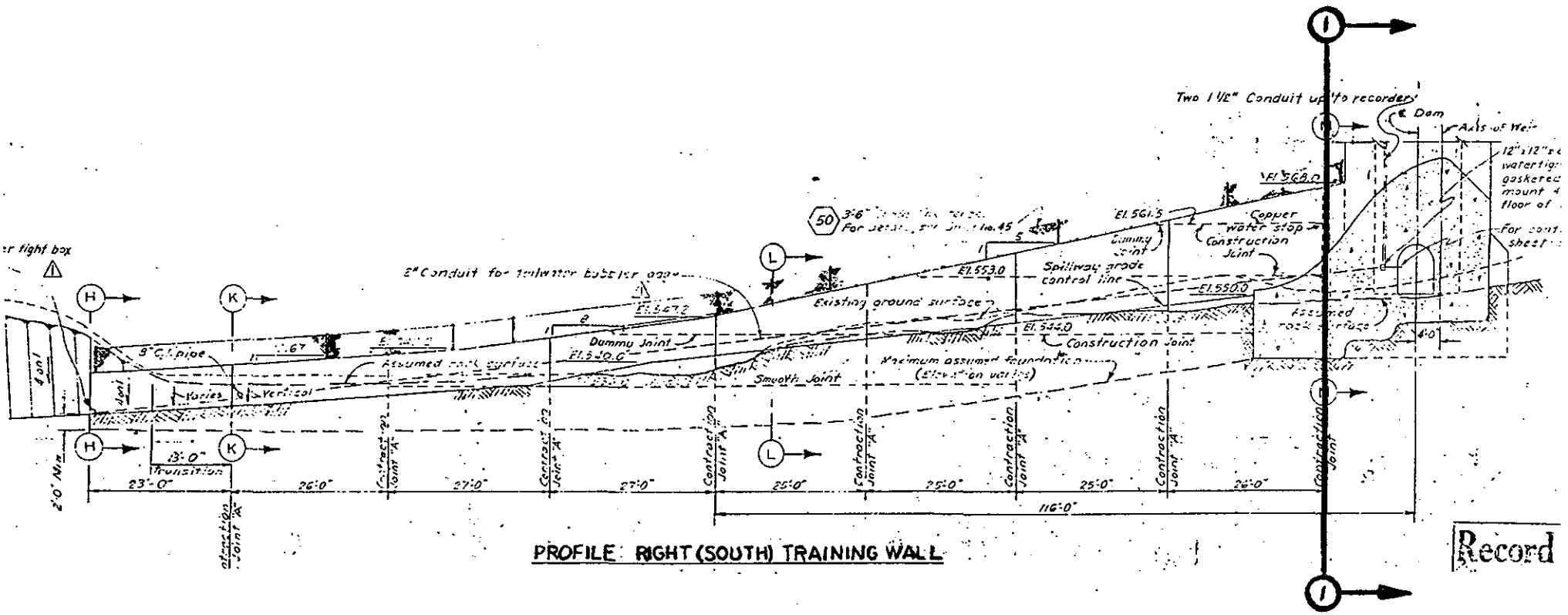
$FS = 12 > 2$ OK

CHECK BEARING PRESSURE

REFERENCE: LOADING CASE II EAST-WEST DIRECTION 3.68 KSF

$$F = 4.05\ KSF \pm 2.45\ KSF + \frac{(3644.59^K)(19.54' - 15.0')(15.0')}{\frac{1}{12}(30')^4}$$

$F_{MAX} = 10.18\ KSF$ OK ($F_{ALLOW} = 40\ KSF$)



PROFILE RIGHT (SOUTH) TRAINING WALL

Record

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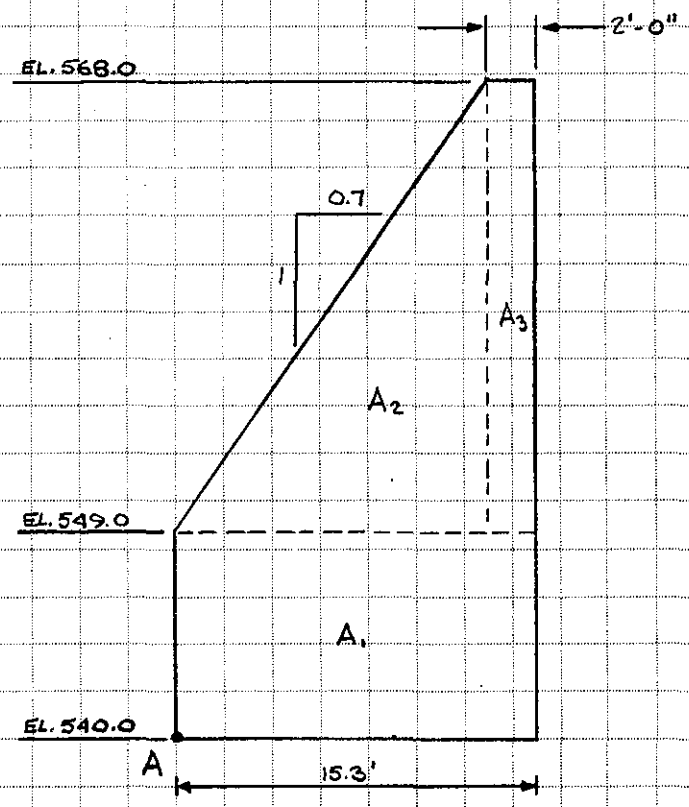
JOB: WESTVILLE DAM STABILITY ANALYSIS
SHEET NO. 133 OF
CALCULATED BY: JMS DATE: 11/18/87
CHECKED BY: LFV DATE: 1/27/88
SCALE

RIGHT (SOUTH) TRAINING WALL STABILITY

SECTION (1)



ITEM	AREA FT²	FORCE K/FT	X-X AXIS ARM	X-X AXIS MOMENT	Y-Y AXIS ARM	Y-Y AXIS MOMENT
A_1	(15.3)(9.00) = 137.70	20.66	7.65	158.01	4.50	92.95
A_2	½(13.3)(19) = 126.35	18.95	8.87	168.05	15.33	290.61
A_3	(2)(19) = 38.00	5.70	14.30	81.51	18.50	105.45
		45.31 K/FT	9.00 FT	407.57 FT-K/FT	10.79 FT	489.01 FT-K/FT

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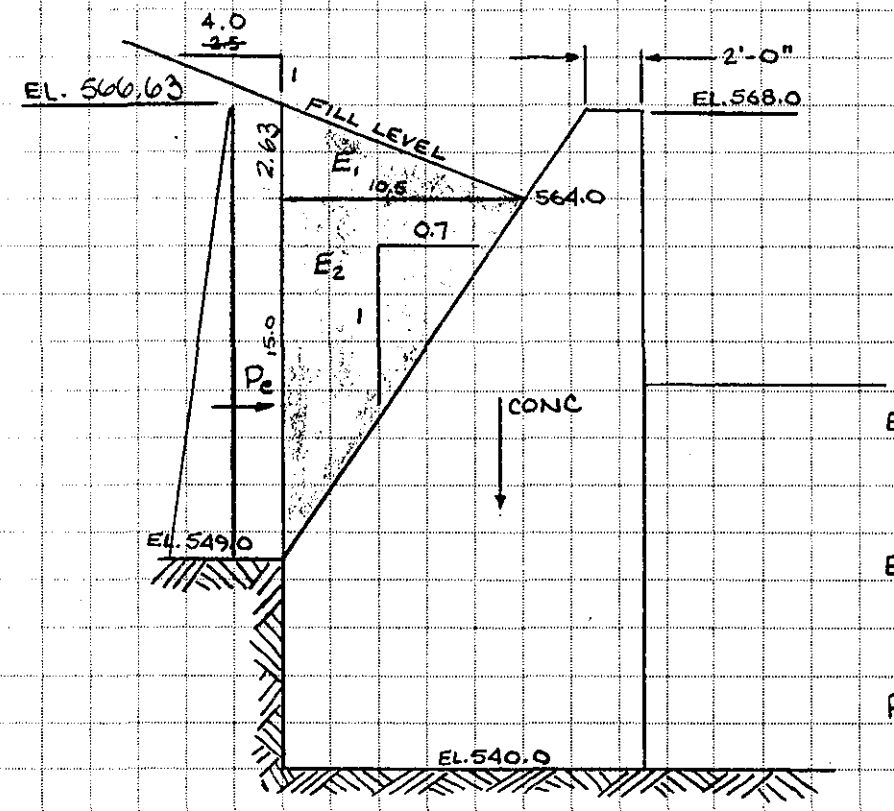
RIGHT (SOUTH) TRAINING WALL STABILITY (CONT)

SECTION ①

LOADING CONDITION CASE I - USUAL LOADING



NO HYDROSTATIC PRESSURE ON SPILLWAY SIDE

$E_1 = (0.135)(\frac{1}{2})(10.5)(2.63)$
$= 1.86^{K/FT}$

$E_2 = (0.135)(\frac{1}{2})(10.5)(15.0)$
$= 10.63^{K/FT}$

$P_e = \frac{1}{2}(0.5)(0.135)(17.63)^2$
$= 10.49^{K/FT}$

ITEM	FORCE	ARM	MOMENT
CONC	45.31 ↓		407.57
E_1	1.86 ↓	3.50	6.51
E_2	10.63 ↓	3.50	37.21
P_e	10.49 →	14.88	156.05
	$\Sigma V = 57.8^{K/FT}$		$\Sigma M = 607.34^{FT-K/FT}$

$\Sigma H = 10.49^{K/FT}$

RIGHT (SOUTH) TRAINING WALL STABILITY (CONT)

SECTION 1

LOADING CONDITION CASE I (CONT)

CHECK OVERTURNING

$\Sigma M / \Sigma V = 607.34 / 57.8 = 10.5$

$0 < 10.5' < 15.3'$
RESULTANT WITHIN THE BASE OK

CHECK SLIDING

$$FS = \frac{(80\ PSL)(15.3')(144\ IN^2/FT^2) + (57800\ \#/FT)\ TAN\ 26.56°}{10490\ \#/FT}$$

$FS = 19.6 > 1.5$ OK

CHECK BEARING PRESSURE

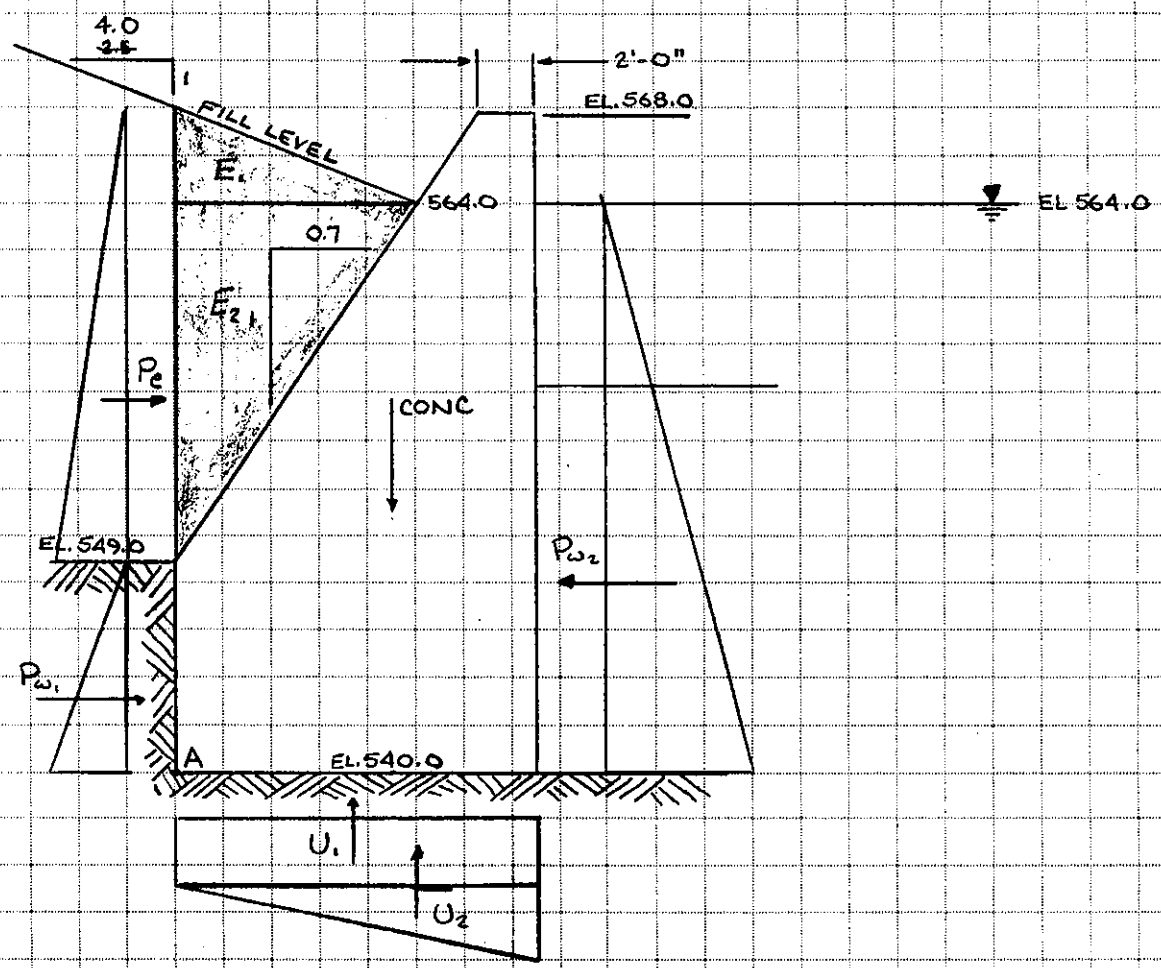
$f_{max} = \frac{2V}{3e}$ WHERE $e = 15.3' - 10.5' = 4.8'$

$f_{max} = \frac{2(57.8^K)}{3(4.8')} = 8.03$ ksf ($f_{allow} = 40$ ksf)
OK

RIGHT (SOUTH) TRAINING WALL STABILITY (CONT)

SECTION ①

LOADING CONDITION CASE II - EXTREME LOADING



$P_{\omega_1} = \frac{1}{2}(0.0625)(9)^2 = 2.53^{K/FT}$

$P_{\omega_2} = \frac{1}{2}(0.0625)(24)^2 = 18.00^{K/FT}$

$U_1 = (0.0625)(9)(15.3) = 8.61^{K/FT}$

$U_2 = [(0.0625)(24) - (0.0625)(9)](15.3)\frac{1}{2} = 7.17^{K/FT}$

RIGHT (SOUTH) TRAINING WALL STABILITY (CONT)

SECTION ①

LOADING CONDITION CASE II (CONT)

ITEM	FORCE	ARM	MOMENT
CONC	45.31 ↓		407.57
E_1	1.86 ↓	3.50	6.51
E_2	10.63 ↓	3.50	37.21
U_1	-8.61 ↑	7.65	-65.87
U_2	-7.17 ↑	10.20	-73.13
P_e	10.49 →	15.40	156.05
P_{w_1}	2.53 →	3.00	7.59
P_{w_2}	-18.00 ←	8.00	-144.00
	$\Sigma V = 42.02^{K}/_{FT}$		$\Sigma M = 331.93^{FT\cdot K}/_{FT}$
	$\Sigma H = -4.98^{K}/_{FT}$		

CHECK OVERTURNING

$\Sigma M / \Sigma V = 331.93 / 42.02 = 7.9'$

$5.1' < 7.9' < 10.2'$

RESULTANT WITHIN MIDDLE THIRD (OK)

CHECK SLIDING

$$FS = \frac{(80\ PSI)(15.3')(144\ IN^2/FT^2) + (4020\ \#/FT)\ TAN\ 26.56^\circ}{4980\ \#/FT}$$

$FS = 40 > 1.5$ (OK)

RIGHT (SOUTH) TRAINING WALL STABILITY (CONT)

SECTION ①

LOADING CONDITION CASE II (CONT)

CHECK BEARING PRESSURE

$$f = \frac{42.02^{K/FT}}{15.3'} \pm \frac{(42.02^{K/FT})(7.9' - 7.65')(7.65')}{\frac{1}{12}(15.3')^3}$$

$$= 2.75 \text{ KSF} \pm 0.27 \text{ KSF}$$

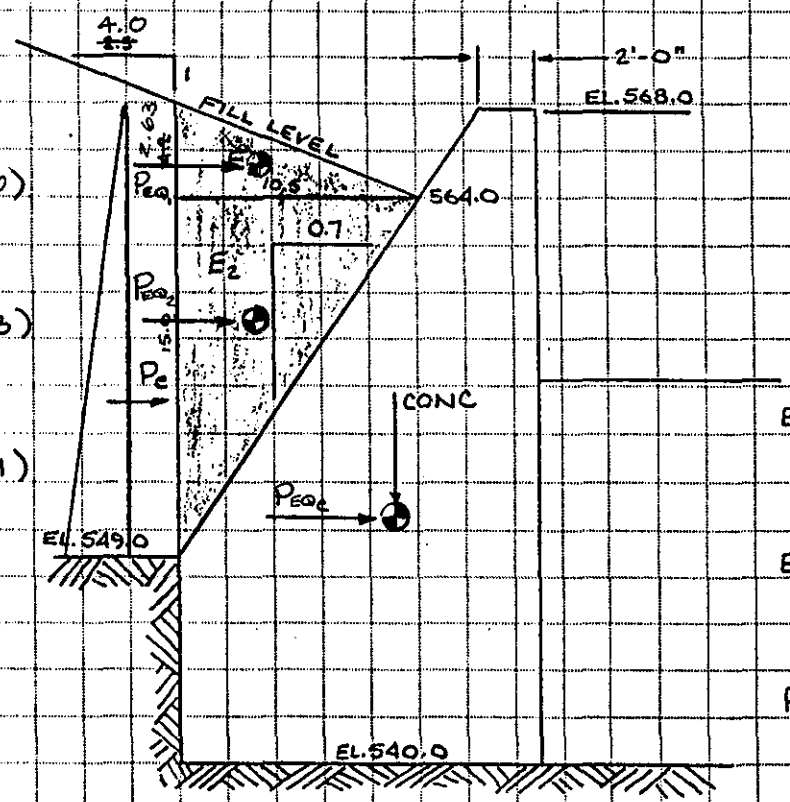
$f_{MAX} = 3.02$ KSF OK ($f_{ALLOW} = 40$ KSF)

$f_{MIN} = 2.48$ KSF

RIGHT (SOUTH) TRAINING WALL STABILITY (CONT)

SECTION ①

LOADING CONDITION CASE ~~R3~~ III - EARTHQUAKE LOADING



$P_{EQ_1} = 0.10(1.86)$
$= 0.19^K$

$P_{EQ_2} = 0.10(10.63)$
$= 1.06^K$

$P_{EQ_c} = 0.10(45.31)$
$= 4.53^K$

NO HYDROSTATIC PRESSURE ON SPILLWAY SIDE

$E_1 = (0.135)(\frac{1}{2})(10.5)(\cancel{4.2}\ 2.63)$
$= \cancel{2.98}^{K/FT}\ 1.86^{K/FT}$

$E_2 = (0.135)(\frac{1}{2})(10.5)(15.0)$
$= 10.63^{K/FT}$

$P_e = \frac{1}{2}(0.5)(0.135)(\cancel{19.2}\ 17.63)^2$
$= \cancel{12.44}^{K/FT}\ 10.49^{K/FT}$

ITEM	FORCE		ARM	MOMENT
CONC	45.31	↓		407.57
E_1	1.86	↓	3.50	6.51
E_2	10.63	↓	3.50	37.21
P_e	10.49	→	15.40	156.05
P_{EQ_1}	0.19	→	24.88	4.73
P_{EQ_2}	1.06	→	19.00	20.14
P_{EQ_c}	4.53	→	10.79	48.88
	$\Sigma V = 57.8^{K/FT}$			$\Sigma M = 681.35^{FT\text{-}K/FT}$
	$\Sigma H = 16.27^{K/FT}$			

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RIGHT (SOUTH) TRAINING WALL STABILITY (CONT)

SECTION 1

LOADING CONDITION CASE III (CONT)

CHECK OVERTURNING

$\Sigma M / \Sigma V = 681.35 / 57.8 = 11.8$

$0 < 11.8' < 15.3'$

RESULTANT WITHIN BASE OK

CHECK SLIDING

$$FS = \frac{(80\ PSI)(15.3')(144\ IN^2/FT^2) + (57800\ \#/FT)\ TAN\ 26.56}{16270\ \#/FT}$$

$FS = 13 > 1.5$ OK

CHECK BEARING PRESSURE

$f_{max} = \frac{2V}{3e}$ WHERE $e = 15.3' - 11.8' = 3.5'$

$f_{max} = \frac{2(57.8^k)}{3(3.5')} = 11.0$ ksf ($f_{allow} = 40$ ksf)

OK