STABILITY ANALYSES & EVALUATIONS (CONT'D)

LEFT ABUTMENT BACKFILL CONDITIONS CONSIST PREDOMINANTLY OF SUBMERGED SOILS RESULTING FROM THE HIGH TRENCH WATER WITH A RELATIVELY SHALLOW DEPTH OF SATURATED SOILS. AS SUCH A WEIGHTED AVERAGE DENSITY WILL BE USED TO REPRESENT THE BACKFILLED SOIL IN-PLACE DENSITY.

$$\bar{\gamma}_{BACKFILL} = \frac{8.5' \cdot 112.4\,pcf + 35' \cdot 50\,pcf}{43.5'}$$

$$\underline{\bar{\gamma}_{BACKFILL} = 62.2\,pcf}$$

$$P_a = \tfrac{1}{2}\gamma_{BACKFILL} \cdot (H_w)^2 \cdot K_a = \tfrac{1}{2} \cdot 62.2\,pcf \cdot (50)^2 \cdot 0.38$$

$$\underline{P_a = 29,546.7\,\#/\text{foot of wall}}$$

$$P_{a_H} = P_a \cdot \cos 35^\circ = 29,541.7\,\#/ft \cdot 0.82$$

$$\underline{P_{a_H} = 24,199.2\,\#/ft \; @ \; 13.33'}$$

$$P_{a_V} = P_a \cdot \sin 35^\circ = 29,541.7\,\#/ft \cdot 0.57$$

$$\underline{P_{a_V} = 16,944.4\,\#/ft \; @ \; 13.33'}$$

WEIGHT OF WALL & FOUNDATION:

$$W_W = \left[\left(\frac{3'+5'}{2} \cdot 40'\right) + (2' \cdot 40') + (\tfrac{1}{2} \cdot 2.5' \cdot 40') + (\tfrac{1}{2} \cdot 7.5' \cdot 11')\right] \cdot \gamma_{conc}$$

$$W_W = [160\,ft^2 + 80\,ft^2 + 50\,ft^2 + 41.25\,ft^2] \cdot 140\,pcf$$

$$\underline{W_W = 331.25 \cdot 140 = 46,375\,\#/foot}$$

$$W_{FDN} = D_F \cdot L_F \cdot \gamma_{concrete} = 3' \cdot 15' \cdot 140\,pcf$$

$$\underline{W_{FDN} = 6300\,\#/foot}$$

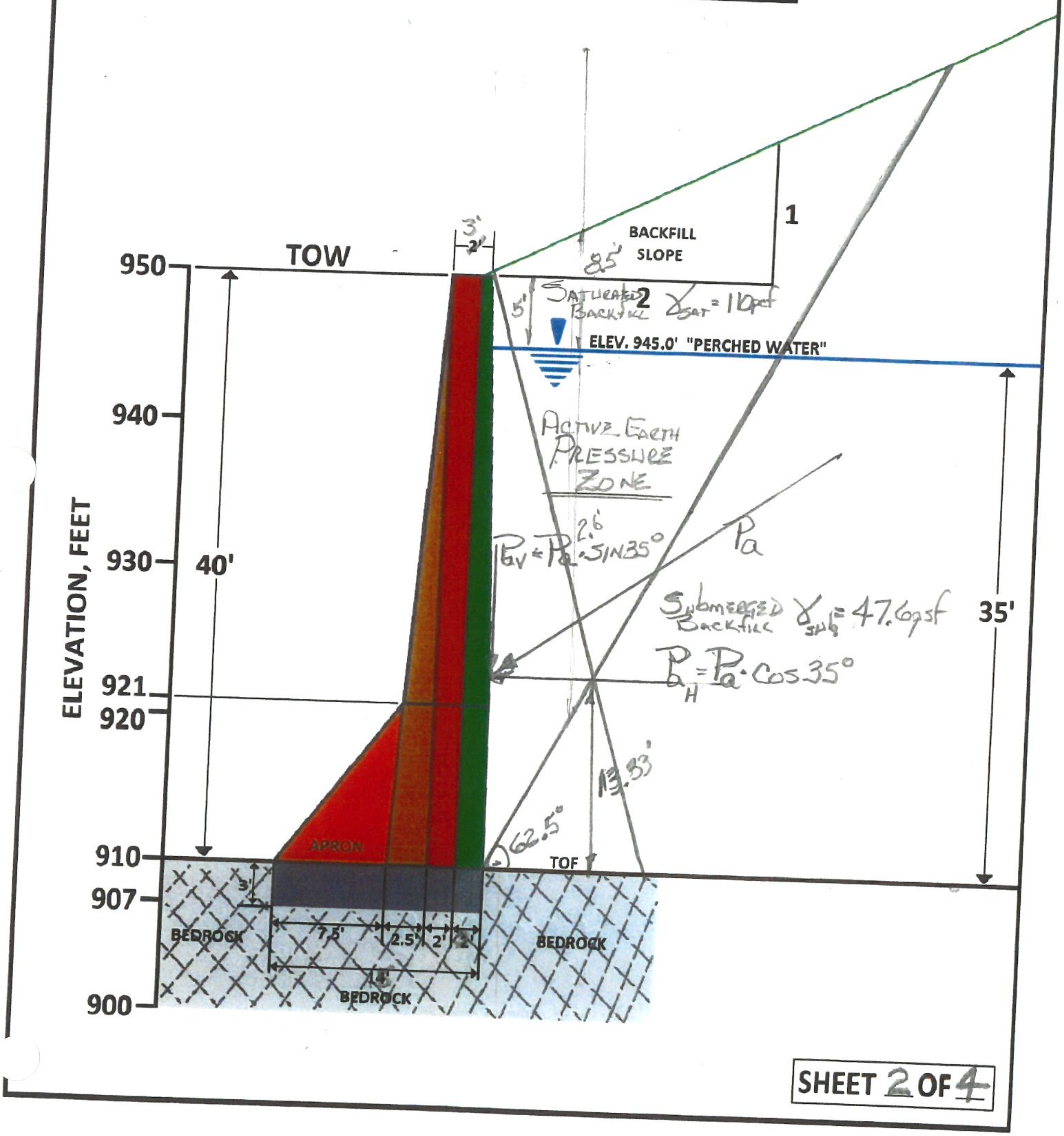
TOTAL VERTICAL LOAD, $W_{TOTAL} = W_W + W_{FDN} + P_{a_V}$

$$W_{TOTAL} = 46,375\,\#/ft + 6300\,\#/ft + 16,944.4\,\#/ft$$

$$\underline{W_{TOTAL} = 69,619.4\,\#/ft}$$

PASSIVE PRESSURE @ HEEL, $P_p = 6,525\,\#/ft$ @ DEPTH OF 2' @ HEEL

Stabilty Analysis (Cont'd)
Left Abutment Wingwall
Section "B"
Scale: 1"= 10'



SHEET 2 OF 4

Stability Analyses & Evaluations (Cont'd)

Factor of Safety Against Sliding, $F.S._{sliding}$:

$$F.S._{sliding} = \frac{P_{P_R} + (P_{a_V} + W_T)\tan\phi_f}{P_{a_H}} = \frac{[6,525 + (16,944.4 + 16,962.8)]1.0}{24,199.2\ \#/ft}$$

$$F.S._{sliding} = \frac{93,088.8\ \#/ft}{24,199.2\ \#/ft}$$

$$F.S._{sliding} = 3.85 > 3.0$$

Good!

Factor of Safety Against Overturning, $F.S._{OT}$:

$$F.S._{OT} = \frac{\Sigma M_R}{\Sigma M_O}:$$

$$F.S._{OT} = \frac{473,835 + 47,250 + 254,166 + 6525}{322,575.3}$$

$F.S._{OT} = 2.4$ w/o Activation of Bearing Capacity Beneath Heel of Wall.

∴ Bearing Capacity Must Be Activated to Resist Overturning

$$M_{Q_{all}} = \tfrac{1}{3} \cdot L_{ftg} \cdot 1125\,psi \cdot 144\ in^2/ft^2 \cdot \frac{L_{ftg}}{6}$$

$$M_{Q_{all}} = 2,025,000\ ft\text{-}lbs/foot$$

$$F.S._{OT_{Available}} = \frac{2,806,776}{322,575.3} = 8.70$$

$$F.S._{OT} \ggg 3.0$$

Very Good!

Sheet 4 of 4

LYSIS AND
IERS –
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SES —

tion 301)
that of concrete

to allowable stresses,
of stress and strain
shall be used, and
except Part IV-B.

ll concrete designed
the values of Table

hose given in Table

xceed those given in

r concrete reinforce-
wing limits:

ring bars
18,000 psi
meter, in
0 percent
by the
s for the
30,000 psi
60,000 psi
24,000 psi
20,000 psi

n yield
30,000 psi

TABLE 1002(a)—ALLOWABLE STRESSES IN CONCRETE

Description		Allowable stresses: For any strength of concrete in accordance with Section 502	For strength of concrete shown below (28 day): $f_c' =$ 2500 psi	$f_c' =$ 3000 psi	$f_c' =$ 4000 psi	$f_c' =$ 5000 psi
Modulus of elasticity ratio: n		$\frac{29{,}000{,}000}{w^{1.5}\,33\sqrt{f_c'}}$				
For concrete weighing 145 lb per cu ft (see Section 1102)	n		10	9	8	7
Flexure: f_c						
Extreme fiber stress in compression	f_c	$0.45f_c'$	1125	1350	1800	2250
Extreme fiber stress in tension in plain concrete footings and walls	f_c	$1.6\sqrt{f_c'}$	80	88	102	113
Shear: v (as a measure of diagonal tension at a distance d from the face of the support)						
Beams with no web reinforcement*	v_c	$1.1\sqrt{f_c'}$	55*	60*	70*	78*
Joists with no web reinforcement	v_c	$1.2\sqrt{f_c'}$	61	66	77	86
Members with vertical or inclined web reinforcement or properly combined bent bars and vertical stirrups	v	$5\sqrt{f_c'}$	250	274	316	354
Slabs and footings (peripheral shear, Section 1207)*	v_c	$2\sqrt{f_c'}$	100*	110*	126*	141*
Bearing: f_c						
On full area		$0.25f_c'$	625	750	1000	1250
On one-third area or less†		$0.375f_c'$	938	1125	1500	1875

*For shear values for lightweight aggregate concrete see Section 1208.
†This increase shall be permitted only when the least distance between the edges of the loaded and unloaded areas is a minimum of one-fourth of the parallel side dimension of the loaded area. The allowable bearing stress on a reasonably concentric area greater than one-third but less than the full area shall be interpolated between the values given.

STABILITY ANALYSES & EVALUATIONS (CONT'D)

LEFT ABUTMENT WINGWALL "SECTION B"
UNUSUAL LOADING CONDITION
REFERENCE SHEET 2

WEIGHT OF "SECTION A" WALL:

$$W_{WALL} = \left[\left(\frac{4+6'}{2}\cdot 40'\right) + \left(\tfrac{1}{2}\cdot 2.5\cdot 40\right) + \left(\tfrac{1}{2}\cdot 7.5'\cdot 11\right)\right] 140\,pcf$$

$$W_{WALL} = [200 + 50 + 20.6]\cdot 140\,pcf = 270.6 \cdot 140\,pcf$$

$$W_{wall} = 37{,}884\ \#/foot$$

$$\bar{X} = \frac{(15'\cdot 28000) + (9.33\cdot 7{,}000) + (5\cdot 2884)}{37{,}884}$$

$$\bar{X} = 13.2'$$

WEIGHT OF FOUNDATION:

$$W_F = 3' \times 16' \times 140\,pcf = 6{,}720\ \#/ft$$

$$\bar{X} = 8\ feet$$

ACTIVE EARTH PRESSURES:

$$P_a = \tfrac{1}{2}\cdot \gamma_{sub}\cdot H^2\cdot K_a = \tfrac{1}{2}\cdot 50\,pcf\cdot (40')^2\cdot 0.38$$

$$P_a = 15{,}200\ \#/foot \qquad P_{a_H} = P_a\cos\phi = 12{,}200\#$$

$$\bar{Y} = 13.33 \qquad P_{a_V} = P_a\sin\phi = 8{,}718\#$$

HYDROSTATIC PRESSURE:

$$P_H = \tfrac{1}{2}\gamma_0 H^2 = \tfrac{1}{2}\cdot 62.4\cdot (40')^2 = 24{,}960\ \#/foot$$

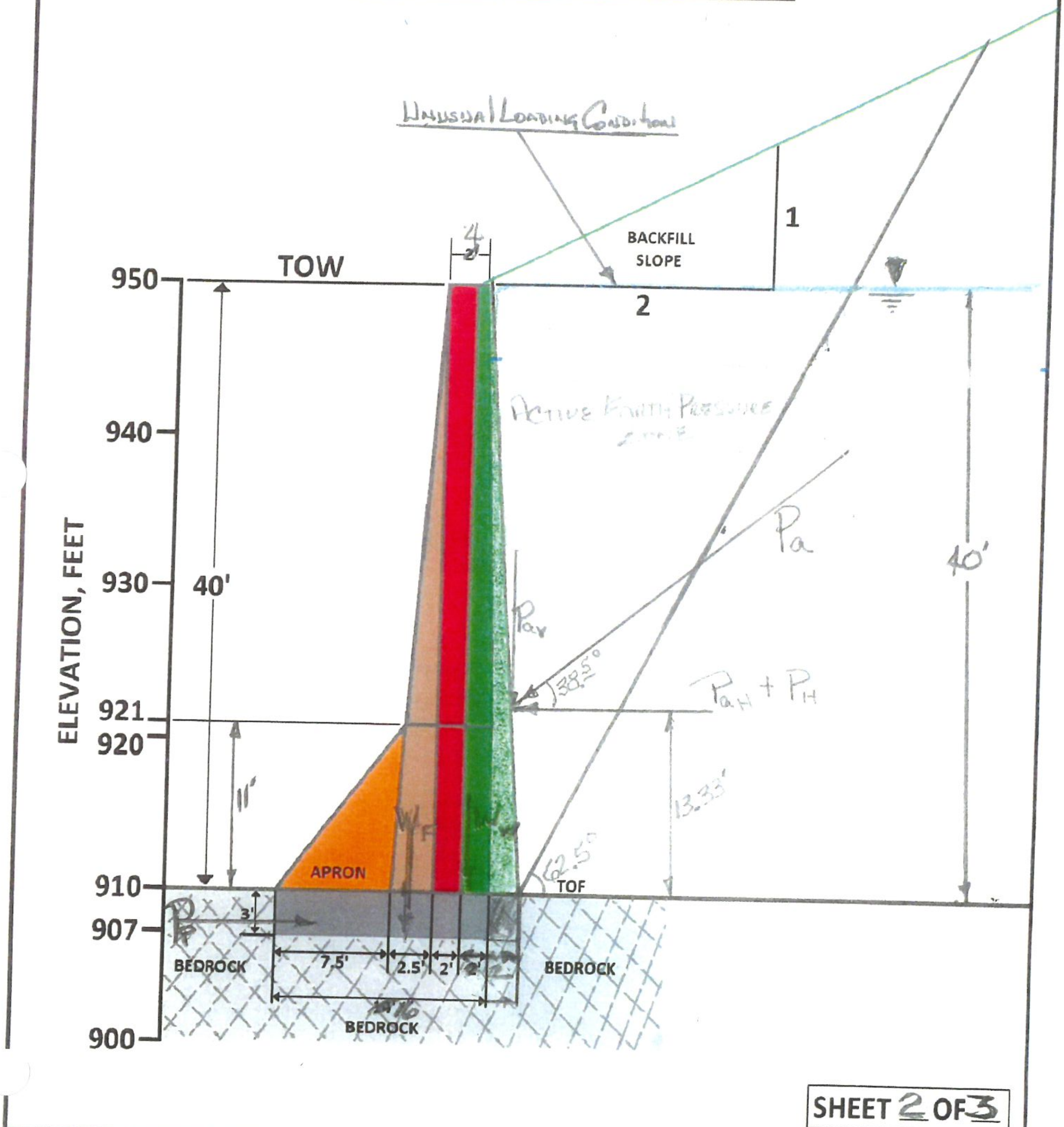
$$\bar{Y} = 13.33'$$

PASSIVE PRESSURE; P_P:

$$P_P = \tfrac{1}{2}\cdot \gamma_{BEDROCK}\cdot H^2\cdot K_p = \tfrac{1}{2}\cdot 145\,pcf\cdot (3')^2\cdot 10$$

$$P_P = 6525\ \#/foot\ @\ 2'\ Below\ TOF$$

Stabilty Analysis (Cont'd)
Left Abutment Wingwall
Section "B"
Scale: 1"= 10'



SHEET 2 OF 3

Stability Analyses & Evaluations (Cont'd)

Factor of Safety Against Sliding, $F.S._{sliding}$:

$$F.S._{sliding} = \frac{(K_{hw} + K_{hf} + P_{aV})\tan\phi_f + P_P}{P_H + P_{aH}}$$

$$F.S._{sliding} = \frac{(37{,}884 + 6720 + 8{,}718)\cdot 1.0 + 6525}{24{,}960 + 12{,}200}$$

$$F.S._{sliding} = \frac{59{,}847}{37{,}160} = 1.61 < 2.0$$

INADEQUATE

Factor of Safety Against Overturning:

$$F.S._{OT} = \frac{\Sigma M_R}{\Sigma M_O} : M_O = (P_H + P_{aH})\cdot l$$

$$M_O = (24{,}960 + 12{,}200)\,13.33'$$

$$M_O = 495{,}342.8 \text{ ft-lbs/foot}$$

$$M_R = K_{hw}\cdot l_1 + K_{hf}\cdot l_2 + P_{aV}\cdot l_3 + P_P\cdot l_4$$

$$M_R = 37{,}884\cdot 13.2' + 6720\cdot 8' + 8718\cdot 13.2' + 6525\cdot 4'$$

$$M_R = 675{,}431.4 \text{ ft-lbs/foot}$$

$$F.S._{OT} = \frac{675{,}431.4}{495{,}342.8} = 1.36$$

$$F.S._{OT} = 1.36 < 2.0 \text{ INADEQUATE}$$

NOT GOOD!!

Stability Analyses & Evaluations (Cont'd)

Left Abutment Wingwall "Section B":

Extreme Loading Conditions:

Normal Loading Values:

$Pa_H = 24,199.2 \text{ \#/foot}$

$P_H = \frac{1}{2} \cdot \gamma_0 \cdot H^2 = \frac{1}{2} \cdot 62.4 \text{ pcf} \cdot (35')^2$

$P_H = 38,220 \text{ \#/foot}$

Factored Normal Loading Conditions:

$Pa_H = 1.10 \cdot 24,199.2 \text{ \#/foot} = 26,619.1 \text{ \#/foot}$

$P_H = 1.10 \cdot 38,220 \text{ \#/foot} = 42,042 \text{ \#/foot}$

$$F.S._{sliding} = \frac{P_{PR} + (P_{aV} + W_T)\tan\phi_f}{(Pa_H + P_H)}$$

$$F.S._{sliding} = \frac{93,088.8 \text{ \#/foot}}{26,619.1 + 42,042} = \frac{93,088.8}{68,661.1}$$

$F.S._{sliding} = 1.36 > 1.0$

Adequate

However, Continuous Monitoring Will Be Necessary - Remediation After 4 to 6 Years - Rock Anchors

Stability Analyses & Evaluations (Cont'd)

Factor of Safety against Overturning:

$$F.S._{OT} = \frac{\Sigma M_R}{\Sigma M_O}:$$

Normal Loading Condition M_O:

$M_{O_{Normal}} = 322,575.3 + 509,472.6$

$M_{O_{Normal}} = 832047.9$ ft-lbs/foot

Factored $M_{O_{Normal}} = 1.10 \cdot 832,047.9$

$\bar{M}_{O_{Normal}} = 915,252.69$

$$F.S._{OT} = \frac{2,806,776}{915,252.7}$$

$F.S._{OT_{Extreme}} = 3.06$ w/ Maximum Qa Developed

w/o Qamax

$F.S._{OT} < 1.0$

Inadequate

Recommendation More Stringent!!

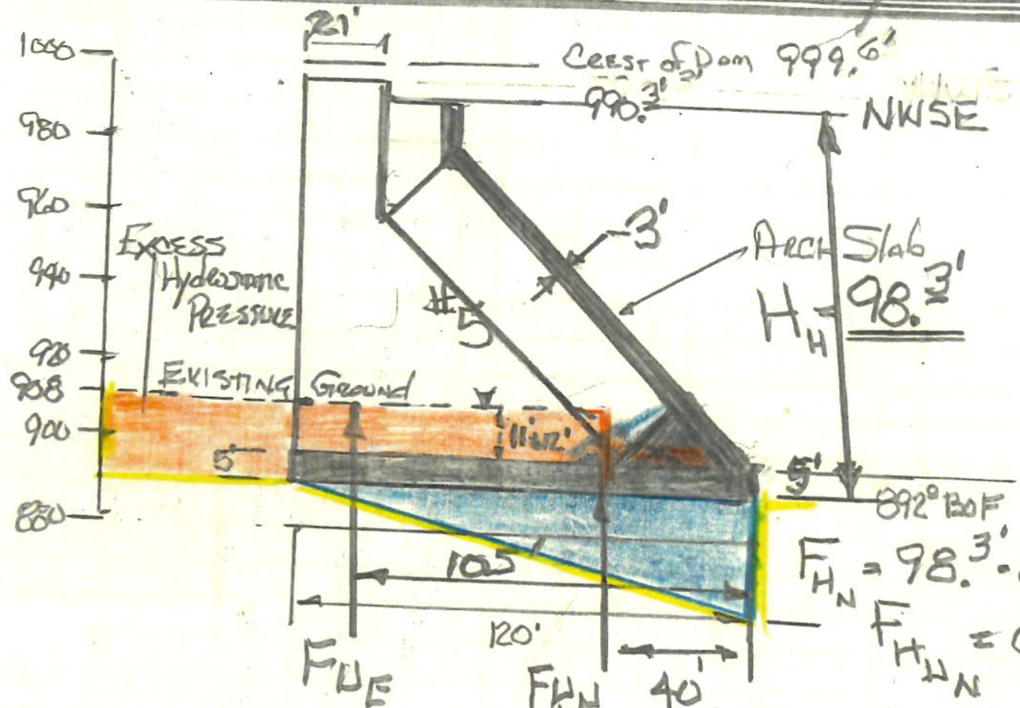
Must Remediate Immediately

Stability Analyses & Evaluations (Cont'd)

Dam Butress No. 5 & Bay No. 4

Condition: Excessive Leakage & Underseepage

Determine Normal & Excessive Hydrostatic Uplift:



$F_{H_N} = 98.3' \cdot 62.4\,pcf$

$F_{H_{U_N}} = 6133.9\,\#/ft^2$

$F_{U_N} = 1/2\, F_{H_{U_N}} \cdot H_H \cdot W = 1,808,887\#$

$F_{H_E} = 16' \cdot 62.4\,pcf = 998.4\,\#/ft^2 @ 40'$

$F_{U_E} = 1/2 \cdot F_{H_E} \cdot H'_H \cdot W' = 47,923.2\#$

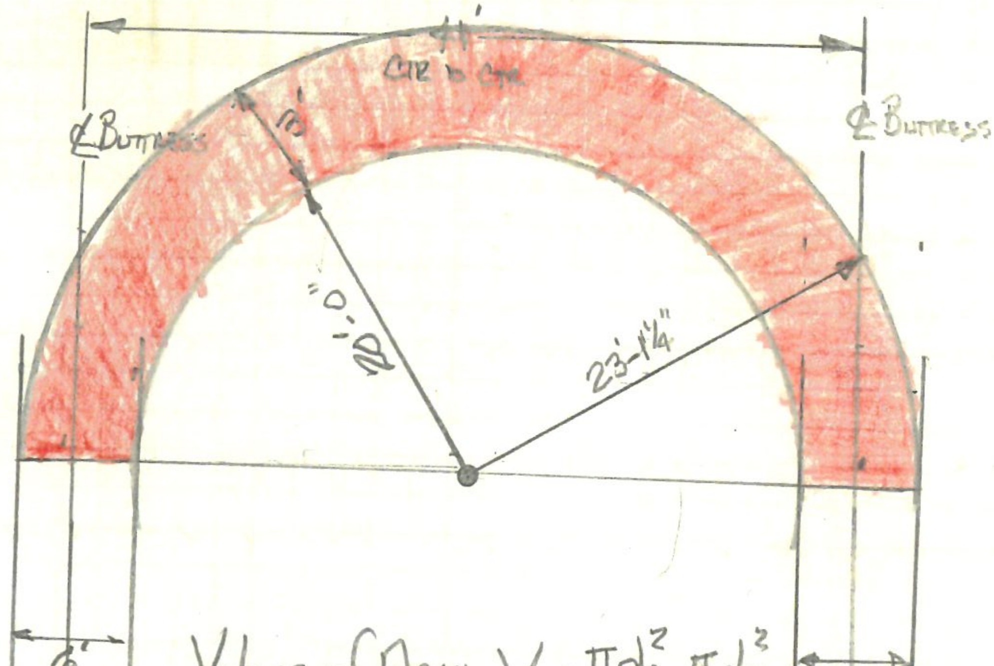
@ 105 feet

$F_{UPLIFT_{TOTAL}} = 1,856,810.3\#$

Stability Analyses & Evaluations (Cont'd)

Determine the Weight of the Buttress & Arch:

Dam Buttress No. 5 supports half of the weight of the Arch of Bay #4 & half of the weight of the Arch of Bay #5 which are the same. As such, the weight of one entire bay arch will be determined for the weight and the load will be in the same manner. Section F-F of the "Original" Design Drawings provides details of the Dam Arch Slabs.



Volume of Arch, $V_a = \frac{\pi d_o^2}{4} - \frac{\pi d_I^2}{4} \cdot L$

$$V_a = \frac{\pi(d_o^2 - d_I^2)}{4} \cdot L; \quad d_o = 23'$$

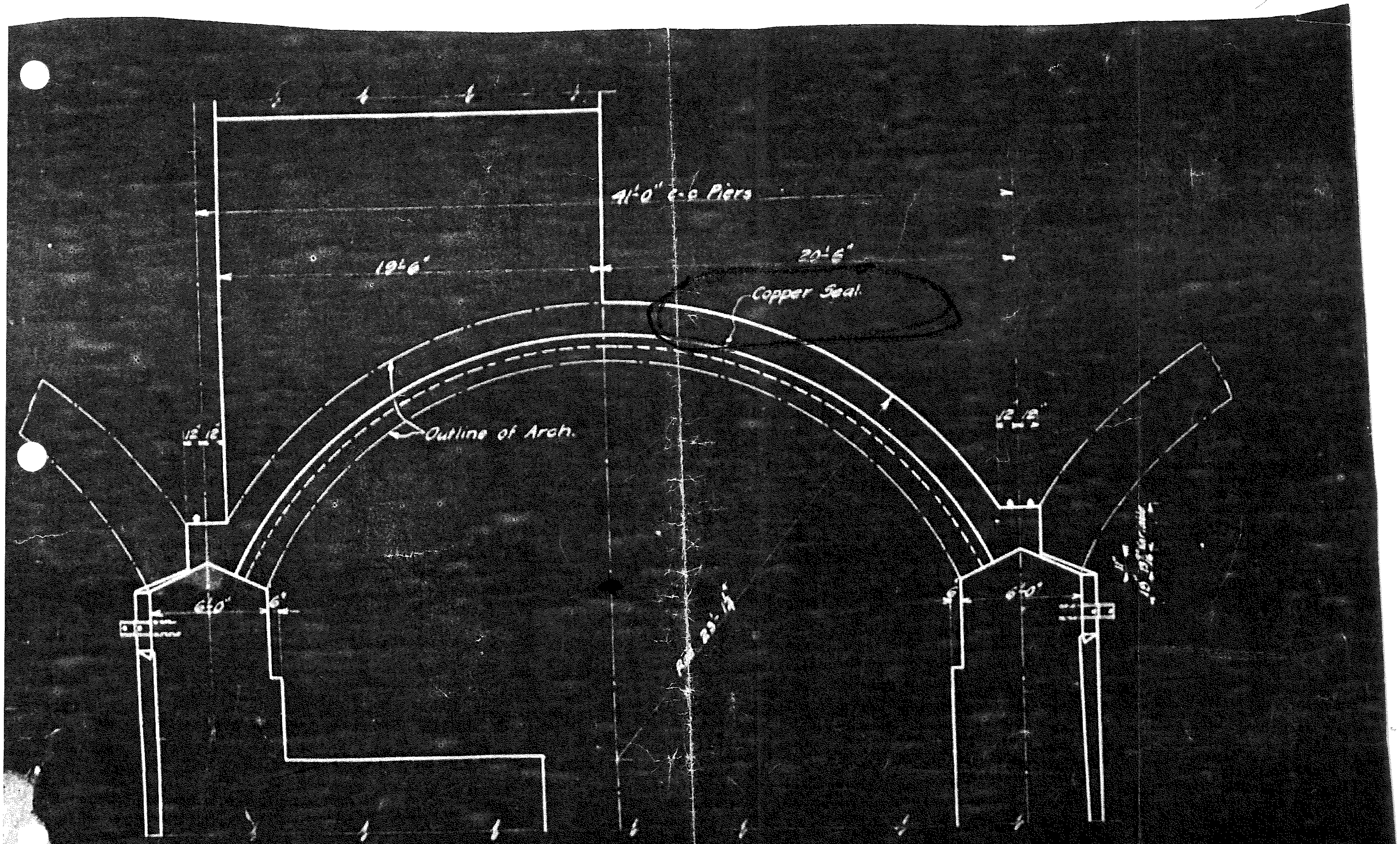
$$V_a = \frac{\pi(529-400)}{4} \cdot 84' \quad d_I = 20'$$

$$V_a = 8{,}510.6 \text{ ft}^3 \quad L = 84 \text{ feet}$$

$$W_a = V_a \cdot \gamma_{concrete} = 8{,}510.6 \text{ ft}^3 \cdot 150 \text{ pcf}$$

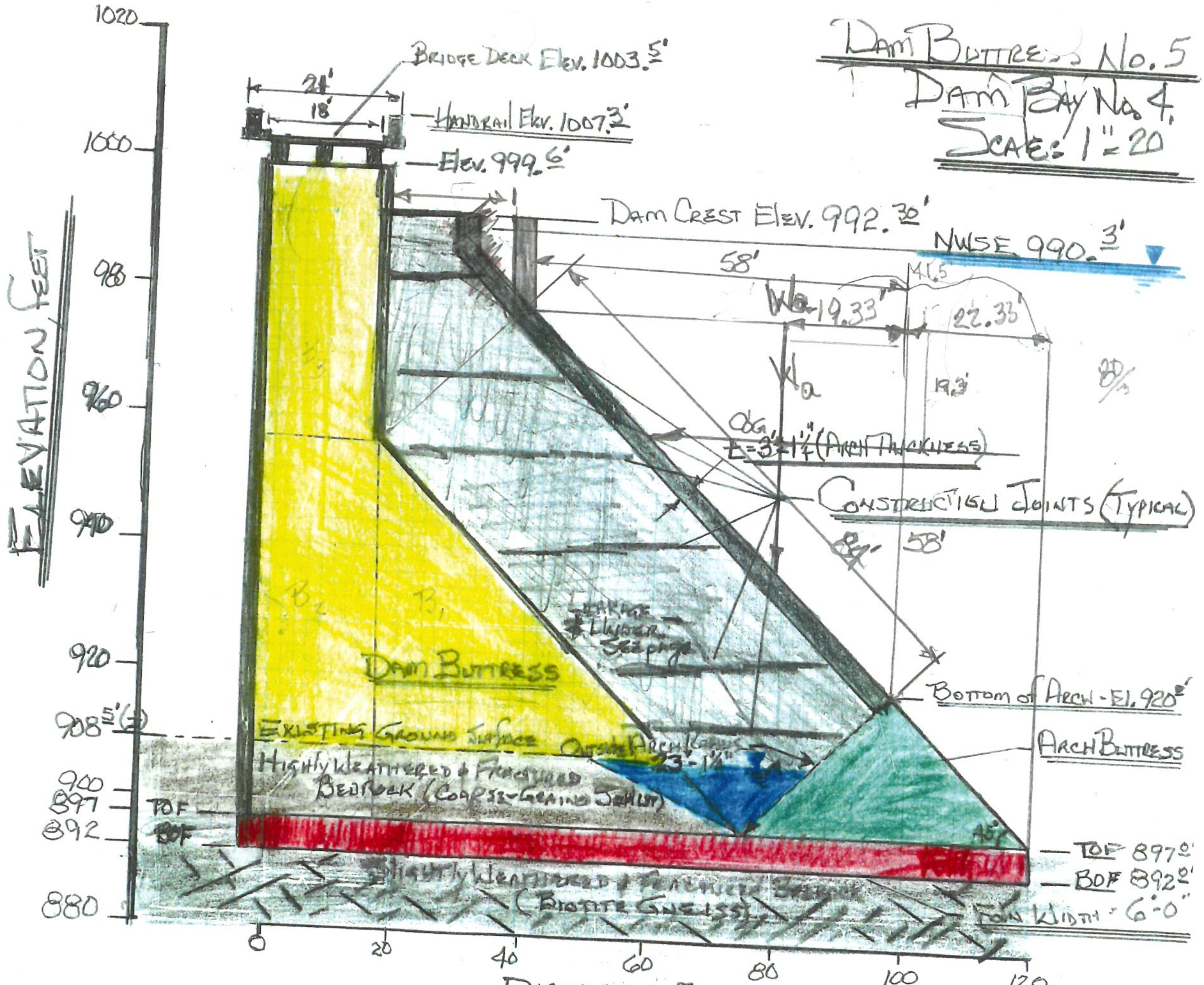
Reference Sheet 3 & 4

$$\boxed{W_a = 127{,}658.6^{\#}}$$



SECTION F - F

Dam Buttress No. 5
Dam Bay No. 4
Scale: 1" = 20'

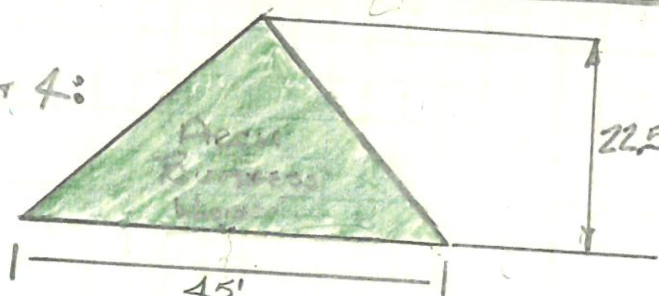


Sheet 4 of 9

Stability Analyses & Evaluations (Cont'd)

Determine Weight of the Arch Buttress:

Reference Sheet 4:



$$W_{AB} = \tfrac{1}{2} B \cdot H \cdot W \cdot \gamma_{CONCRETE}$$

$$W_{AB} = \tfrac{1}{2} \cdot 45' \cdot 22.5' \cdot 43' \cdot 150\,pcf$$

$$\underline{W_{AB} = 3{,}265{,}312.5\#}$$

Determine Weight of Foundation:

$$W_{FDN} = 120' \times 5' \times 6' \cdot 150\,pcf = 540{,}000$$

Reference Sheet 4: $\underline{W_{FDN} = 540{,}000\#}$

Determine Weight of Vertical Portion of Arch:

Reference Sheet 4:

$$\text{Area of Arch / Ft Length} = \frac{\pi(d_o^2 - d_I^2)}{4}$$

$$A_a = \frac{\pi \cdot (529 - 400)}{4} \qquad d_o = 23'; d_I = 20'$$

$$\underline{A_a = 101.3\,ft^2}$$

$$W_a = A_a \cdot L \cdot \gamma_{CONCRETE}$$

$$W_a = 101.3\,ft^2 \cdot \frac{15' + 35'}{2} \cdot 150\,pcf$$

$$\underline{W_a = 379{,}936.4\#}$$

Stability Analyses & Evaluations (Cont'd)

Determine the Weight of the Dam Buttress:

Reference Sheet 4:

$$W_{B_1} = \tfrac{1}{2} \cdot B \cdot H \cdot W \cdot \gamma_{concrete} = \tfrac{1}{2} \cdot 58' \cdot 60' \cdot 4' \cdot 150\,pcf$$

$$\underline{W_{B_1} = 1{,}044{,}000\ \#}$$

$$W_{B_2} = B \cdot H \cdot W \cdot \gamma_{concrete} = 20' \cdot 60' \cdot 4' \cdot 150\,pcf$$

$$\underline{W_{B_2} = 2{,}880{,}000\ \#}$$

$$W_{B_3} = B \cdot H \cdot W \cdot \gamma_{concrete} = 20' \cdot 40' \cdot 3' \cdot 150\,pcf$$

$$\underline{W_{B_3} = 360{,}000\ \#}$$

$$W_{B_{TOTAL}} = W_{B_1} + W_{B_2} + W_{B_3} = 4{,}284{,}000\ \#$$

$$\underline{W_{B_{TOTAL}} = 4{,}284{,}000\ \#}$$

Determine the Weight of One Section of Bridge

$$W_{BRIDGE} = W_{HANDRAILS} + W_{DECK} + W_{BEAMS}$$

$$W_{HANDRAILS} = 2[4' \times 1.5 \times 41] \cdot 150\,pcf = 73{,}800\ \#$$

$$W_{DECK} = [21' \times 0.75' \cdot 41'] \cdot 150\,pcf = 96{,}862.5\ \#$$

$$W_{BEAMS} = 3 \cdot [2' \times 2' \times 41'] \cdot 150\,pcf = 73{,}800\ \#$$

$$\underline{W_{BRIDGE} = 244{,}462.5\ \#}$$

Stability Analyses & Evaluations (Cont'd)

Total Weight of Buttress, Arch, Bridge & Water

$$W_T = W_B + W_A + W_{AB} + W_{VA} + W_{FDN} + W_{Bridge} + W_W$$

$$W_T = 4{,}284{,}000^{\#} + 127{,}658.6 + 3{,}265{,}312.5^{\#} + 379{,}936.4^{\#} + 540{,}000 + 244{,}462.5^{\#} + \underbrace{\tfrac{1}{2} \cdot 80' \cdot 80' \cdot 41' \cdot 62.4^{\#}/ft^3}_{8{,}186{,}880^{\#}}$$

$$\underline{W_T = 19{,}228{,}412.5^{\#}}$$

Determine Total Uplift Force:

$$F_{uplift\ normal} = 1{,}808{,}887.1^{\#}$$

$$F_{uplift\ excessive} = 47{,}923.2^{\#}$$

$$\underline{\text{Total uplift} = 1{,}856{,}810.3^{\#}}$$

Determine Lateral Water Load:

$$F_{H2O} = \tfrac{1}{2} \cdot \gamma_0 \cdot H^2 \cdot L = \tfrac{1}{2} \cdot 62.4 \cdot (80')^2 \cdot 41'$$

$$\underline{F_{H_2O} = 8{,}186{,}880.0^{\#}}$$

Stability Analyses & Evaluations (Cont'd)

Factor of Safety Against Sliding Failures:

$$F.S._{Sliding} = \frac{W_T \cdot \tan\phi_f - F_{uplift}}{F_{H2O}}$$

$$F.S._{Sliding} = \frac{(19,228,412.5^{\#} \cdot 1.0) - 1,856,810.3^{\#}}{8,186,880.0}$$

$$F.S._{Sliding} = 2.12 \ll 3.0$$

VERY INADEQUATE

POTENTIAL FAILURE LOCATION

Factor of Safety Against Overturning Failure

$$F.S._{OT} = \frac{M_R}{M_O} \; ; M_O = F_{H_2O} \cdot l_1 + F_a \cos 45° \cdot l_2 + F_{UN} \cdot l_3 + F_{HE} \cdot l_4$$

$M_O = 8,186,880 \cdot 32.8' +$

$127,658.6 \cdot 0.72 \cdot 47.5' +$

$1,808,887.1^{\#} \cdot 80' +$

$47,923.2^{\#} \cdot 15'$

$$M_O = 418,325,404.1 \text{ ft-lbs}$$

Stability Analyses & Evaluations (Cont'd)

Determine the Moment Resisting Overturning:

$$M_R = W_a \cdot l_1 + W_{AB} \cdot l_2 + W_{a_V} \cdot l_3 + W_{Buttress} \cdot l_4 + W_{Bridge} \cdot l_5$$

$$M_R = 127{,}658.6 \cdot 82.5 + 379{,}936.4 \cdot 42' + 3{,}265{,}312.5^{\#} \cdot 102' + 19{,}228{,}412.5^{\#} \cdot 100' + 244{,}462.5^{\#} \cdot 10.5'$$

$$M_R = 10{,}531{,}834.5 + 15{,}957{,}328.8 + 333{,}061{,}875.0 + 1{,}922{,}841{,}250 + 2{,}566{,}856.3$$

$$M_R = 2{,}284{,}959{,}144.6 \text{ Ft-lbs}$$

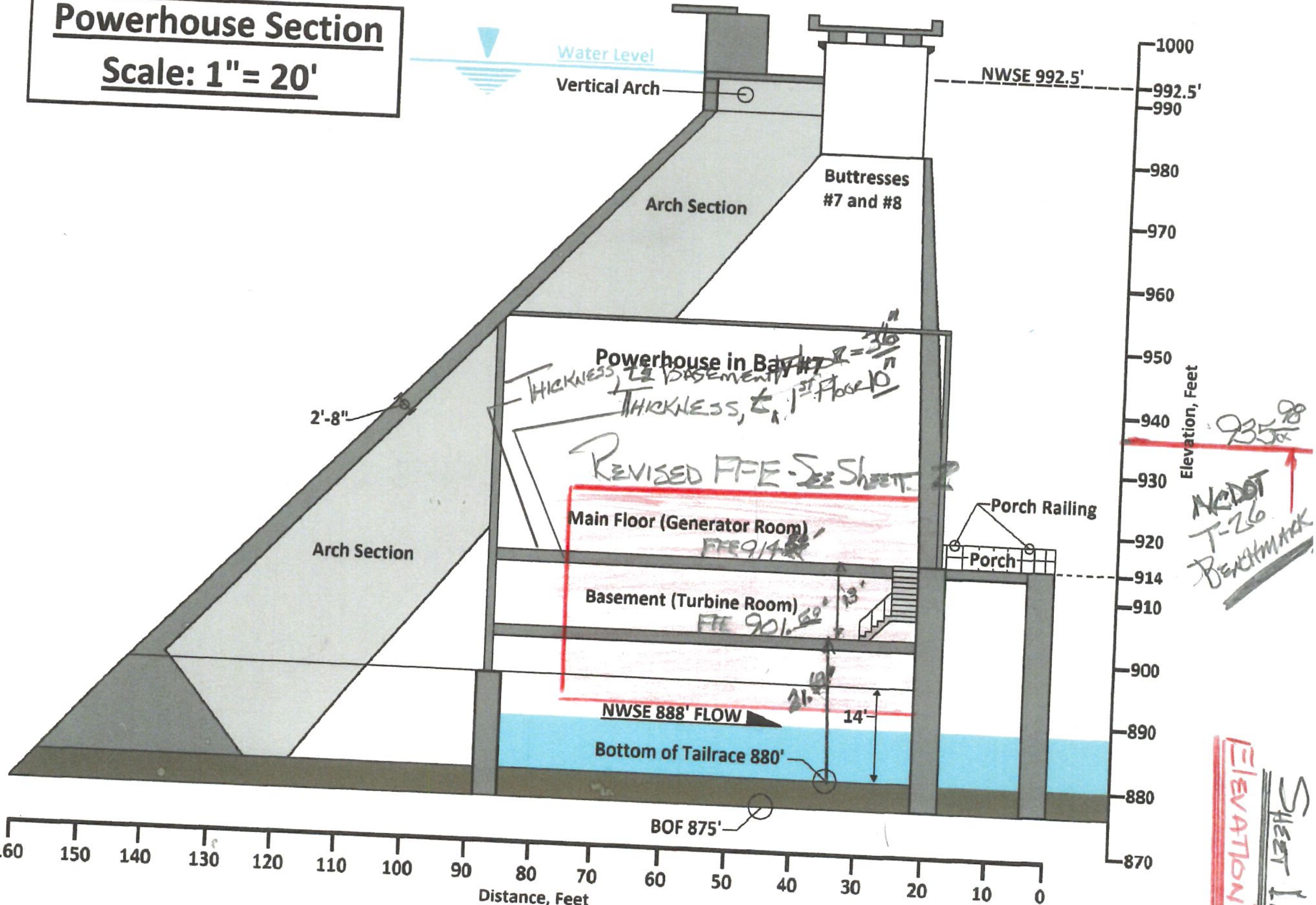
$$F.S._{OT} = \frac{2{,}284{,}959{,}144.6 \text{ Ft-lbs}}{418{,}325{,}404.1 \text{ Ft-lbs}}$$

$$F.S._{OT} = 5.46 >> 3.0$$

Very Good

Powerhouse Section

Scale: 1"= 20'



SHEET 1 OF 13

ELEVATION REVISION

VERIFICATION OF 1ST DISCREPENCY IN ORIGINAL PLANS & EXISTING ELEVATIONS

ORIGINAL PLANS ELEV. OF POWERHOUSE MAIN FLOOR = 911.0'

ORIGINAL PLANS ELEV. OF POWERHOUSE BASEMENT FLR = 900.0'

PHASE I ELECTRONIC SURVEY:

NCDOT T-26 BENCHMARK ADJACENT TO PAVED ENTRANCE ROADWAY

ELEV. 935.98'

READINGS OF FOUR (4) FORESIGHT SHOTS ON MAIN POWERHOUSE FLOOR (GENERATOR ROOM FLOOR)

- -21.32' @ FRONT DOOR JAM
- -21.29' 1ST INSIDE FLOOR SHOT
- -21.28' 2ND INSIDE FLOOR SHOT
- -21.28' 3RD INSIDE FLOOR SHOT

AVERAGE FORESIGHT -21.29'

REVISED 1ST FFE (GENERATOR ROOM FLOOR)

TBM ELEV. 935.98'
FORSIGHT -21.29'

1ST FFE 914.69 FEET

DIRECT MEASUREMENT & ADDITIONAL FORESIGHT TO BASEMENT FLOOR 13.00 FEET

BASEMENT & TURBINE ROOM FFE (REVISED) 901.69 FEET

BOTTOM OF TAILRACE = 880.00'

DISTANCE FROM FFE TURBINE ROOM TO BOTTOM OF TAILRACE = 21.69

DETERMINE ALL HYDROSTATIC PRESSURES & FORCES:

RESULTANT LOCATION OF UPLIFT:

$$\bar{X} = \frac{2{,}111{,}616^{\#}\cdot 45' + 8{,}255{,}520 \cdot 120'}{10{,}367{,}136^{\#}} \leftarrow P_{uplift_{TOTAL}}$$

$$\bar{X} = 104.7 \text{ FEET}$$

RESULTANT & LOCATION OF RESULTANT OF WEIGHT

$$\bar{X} = \frac{W_{w_1}\cdot l_1 + W_{w_2}\cdot l_2}{W_{w_1} + W_{w_2}} = \frac{(W_{w_1}\cdot 45') + W_{w_2}\cdot 30')}{(W_{w_1} + W_{w_2})}$$

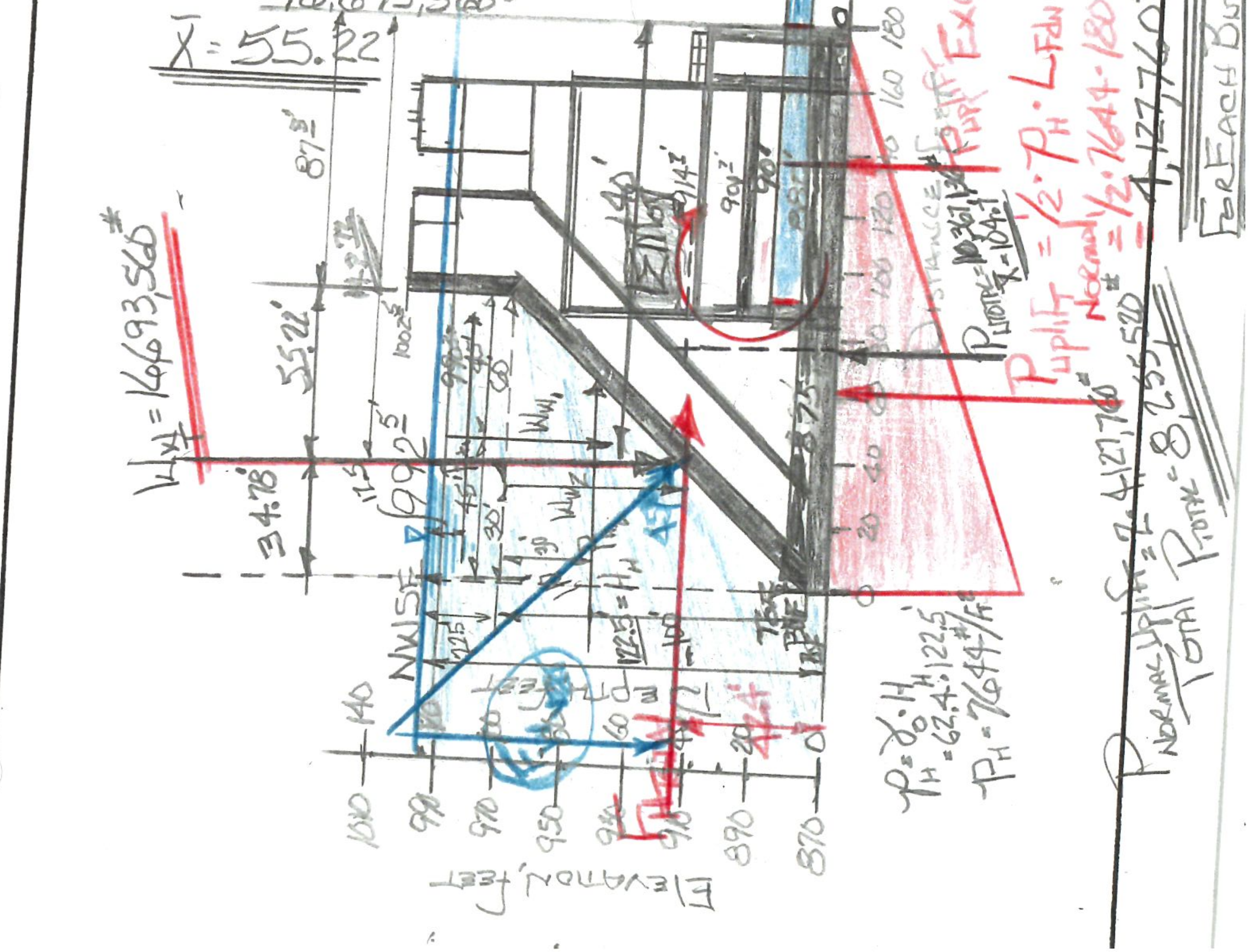
$$W_{w_1} = (90\cdot 22.5\cdot 41')\cdot 62.4\,pcf = 5{,}180{,}760^{\#}$$

$$W_{w_2} = (1/2\cdot 100'\cdot 90'\cdot 41')\cdot 62.4 = 11{,}512{,}800^{\#}$$

$$W_{TOTAL} = 16{,}693{,}560^{\#}$$

$$\bar{X} = \frac{921{,}743{,}550 \text{ ft-lbs}}{16{,}693{,}560^{\#}}$$

$$\bar{X} = 55.22'$$



Horizontal Force of Water on Powerhouse:

$$F_{H_{TOTAL}} = F_{H_{U/S}} - F_{H_{TAILRACE}}$$

$$F_{H_{TOTAL}} = \tfrac{1}{2} \cdot H_{US}^2 \gamma_0 \cdot W_{PH}' - \tfrac{1}{2} \cdot H_{TAILRACE}^2 \cdot \gamma_0 \cdot W_{PH} =$$

$$\tfrac{1}{2} \cdot \gamma_0 \cdot W_{PH}(H_{U/S}^2 - H_{TAILRACE}^2) =$$

$$\tfrac{1}{2} \cdot 62.4 \cdot 41'(122.5'^2 - 8'^2)$$

$$\underline{F_{H_{TOTAL}} = 19,114,126.2 \text{ lbs.}}$$

$$F_{H_{TAILRACE}} = 81,868.8^{\#}$$

$$F_{H_{U/S}} = 1,958,775^{\#}$$

$$\bar{X} = \frac{F_{H_{US}} \cdot \frac{122.5}{3} - F_{TAILRACE} \cdot \frac{8}{3}}{F_{H_{U/S}} - F_{H_{TAILRACE}}}$$

$$\bar{X} = \frac{79,983,312.5 - 218,316.8}{1,876,906.2}$$

$$\underline{\bar{X} = 42.4 \text{ FEET}}$$

DETERMINE THE MOMENT OF OVERTURNING:

REFERENCE SHEETS 3 & 4:

$$\Sigma M_{OT} = F_{H_{TOTAL}} \cdot l_1 + \underbrace{P_{uplift_{NORMAL}} \cdot l_2 + P_{uplift_{EXCESS}}}$$

$$\Sigma M_{OT} = F_{H_{TOTAL}} \cdot \bar{Y} + P_{uplift_{TOTAL}} \cdot X$$

$$\Sigma M_{OT} = 1{,}876{,}906.2^{\#} \cdot 42.4 \text{ feet} + 10{,}367{,}136^{\#} \cdot 104.7 \text{ feet}$$

$$\Sigma M_{OT} = 79{,}580{,}822.9 \text{ ft-lbs} + 1{,}085{,}439{,}139.2 \text{ ft-lbs}$$

$$\Sigma M_{OT} = 1{,}895{,}878{,}890.1 \text{ ft-lbs}$$

DETERMINE THE WEIGHT OF BUTTRESSES #7 & 8; WEIGHT OF ARCH BETWEEN BUTTRESSES #7 & #8; WEIGHT OF THE ARCH BUTTRESS; WEIGHT OF #7 & #8 BUTTRESS FOUNDATIONS; WEIGHT OF VERTICAL PORTION OF THE ARCH; AND RESULTANT FORCE & LOCATION OF RESULTANT

REFERENCE SHEET 6 FOR LOCATIONS & WEIGHTS.

WEIGHT OF BRIDGE SECTION: REFERENCE SHEET 6 OF BUTTRESS #5 CALCULATIONS

$$W_{BRIDGE} = 244{,}462.5^{\#} \text{ @ } \bar{X} = 34' \text{ from Heel}$$

WEIGHT OF VERTICAL PORTION OF ARCH, W_{A_V}:

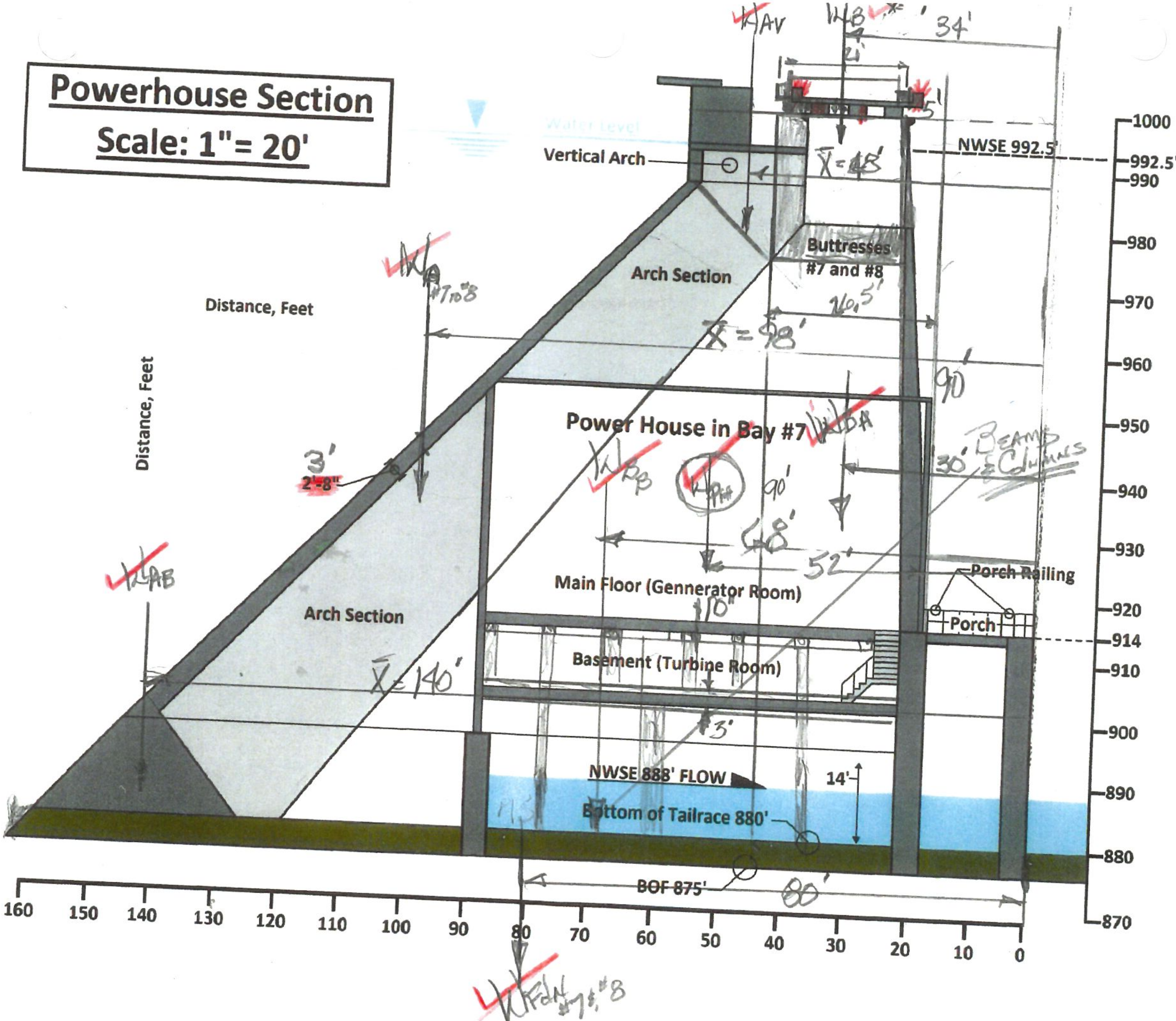
$$W_{a_V} = 101.3 \text{ ft}^2 \cdot \bar{X}_V \cdot \gamma_{CONCRETE} = 101.3 \text{ ft}^2 \cdot \left(\frac{10' + 23'}{2}\right) \cdot 140 \text{ pcf}$$

$$W_{a_V} = 234{,}003 \text{ @ } \bar{X} = 48' \text{ from Heel.}$$

WEIGHT OF SLOPING PORTION OF THE ARCH, $W_{a_{\#7 \text{ to } \#8}}$:

$$W_{a_{\#7 \text{ to } \#8}} = \frac{\pi(529 - 400)}{4} \cdot 118' \cdot 140 \text{ pcf}$$

$$W_{a_{\#7 \text{ to } \#8}} = 1{,}673{,}746.3^{\#} \text{ @ } \bar{X} = 98' \text{ from Heel.}$$



Powerhouse Section
Scale: 1"= 20'
Water Level
Vertical Arch
NWSE 992.5'
Buttresses #7 and #8
Arch Section
Power House in Bay #7
Main Floor (Gennerator Room)
Basement (Turbine Room)
Porch Railing
Porch
NWSE 888' FLOW
Bottom of Tailrace 880'
BOF 875'
14'
Arch Section
Distance, Feet
Distance, Feet
3'
2'-8"
34'
21'
$\bar{X}$ = 48'
$\bar{X}$ = 98'
$\bar{X}$ = 140'
90'
90'
68'
52'
30' Beams & Columns
10"
3'
80'
1000
992.5'
990
980
970
960
950
940
930
920
914
910
900
890
880
870
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

Weight of the Arch Buttress, W_{A_B}:

$$W_{A_B} = \tfrac{1}{2} \cdot B \cdot H \cdot L \cdot \gamma_{concrete} = \tfrac{1}{2} \cdot 32' \cdot 18' \cdot 41' \cdot 140\,pcf$$

$$W_{A_B} = 1{,}653{,}120\,\# \;@\; \bar{X} = 140' \text{ from Heel}$$

Weight of Foundations of Buttresses #7 & #8:

$$W_{Fdn_{\#7\&\#8}} = 2 \cdot [160' \cdot 6' \cdot 5' \cdot 140\,pcf]$$

$$W_{Fdn_{\#7\&8}} = 1{,}344{,}000 \;@\; \bar{X} = 80' \text{ from Heel}$$

Weight of Section A of Buttresses #7 & #8, $W_{B_{A_{7\&8}}}$:

$$W_{BA_{7\&8}} = 2 \cdot [26.5' \cdot 114' \cdot 6' \cdot 140\,pcf] - 2 \cdot [\tfrac{1}{2} \cdot 5' \cdot 80' \cdot 4' \cdot 140\,pcf]$$

$$W_{BA_{7\&8}} = 5{,}075{,}280\,\# - 224{,}000\,\#$$

$$W_{BA_{7\&8}} = 4{,}851{,}280\,\# \;@\; 30' \text{ from Heel}$$

Weight of Section B of Buttresses #7 & #8, $W_{B_{B_{7\&8}}}$:

$$W_{BB_{7\&8}} = 2 \cdot [\tfrac{1}{2} \cdot 74' \cdot 90' \cdot 6' \cdot 140\,pcf]$$

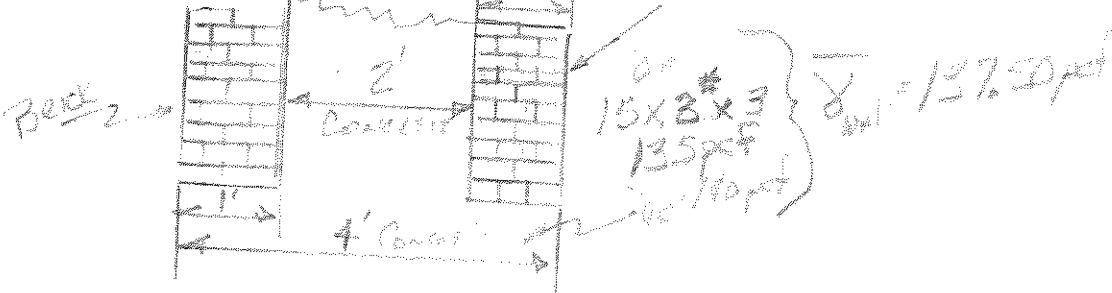
$$W_{BB_{7\&8}} = 5{,}594{,}400\,\# \;@\; \bar{X} = 67.67' \text{ from Heel}$$

Weight of Parapet Two Upper Walls, $W_{P\&S}$:

$$W_{P\&S} = [(1.5' \cdot 18' \cdot 41') + (4' \times 4' \times 32') \cdot 2]\, 140\,pcf$$

$$W_{P\&S} = 298{,}340\,\# \;@\; \bar{X} = 10.5' \text{ from Heel}$$

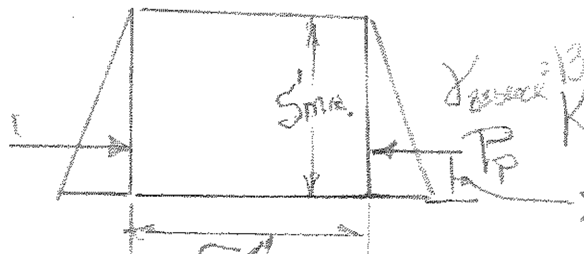
Walls:



DETERMINATION of SIDE FRICTION on FOUNDATIONS

$K_o = 1 - \sin\phi = 1 - \sin 55^\circ = 1 - 0.819 = \underline{0.18}$

FOUNDATION & ARCH BUTTRESS EMBEDMENT DETAIL



$$\Sigma P_{P_T} = \left\{ \left[\tfrac{1}{2}\, \gamma_{gravel}\, H^2_{footing} \cdot L_{ftg} \right] + \left[\tfrac{1}{2} \cdot \gamma_{gravel} \cdot H_{arch\,ftg}^2 \cdot L_{arch} \right] \right\} K_o$$

$$\Sigma P_{P_{Embed}} = \left\{ \left[\tfrac{1}{2} \cdot 135 pcf \cdot (5)^2 \cdot (4 \cdot 160) \right] + \left[\tfrac{1}{2} \cdot 135 pcf \cdot (5)^2 \cdot (2 \cdot 41) \right] \right\} K_o$$

$$\Sigma P_{P_{Embedment}} = 0.18 \{ 1,080,000 + 24,907.5 \}$$

$$\underline{\Sigma P_{P_{Embedment}} = 1,104,907.50\ \#}$$

WEIGHT OF POWERHOUSE, W_{PH}:

$$W_{PH} = W_{roof} + W_{1^{st}\,Floor} + W_{Basement} + W_{Walls} + W_{Beams\,\&\,Columns}$$

$$W_{PH} = 140\,pcf\left[(1'\cdot 41'\cdot 70') + (1'\cdot 41'\cdot 70') + (3'\cdot 41'\cdot 70')\right] + \left[2([illegible]0'\times 70'\times 4) + 2(41'\times 70'\times [illegible])\right]\cdot 137;$$

$$\left[(25\ \text{Beams} = 146{,}062.5^{\#}) + (20\ \text{Columns} = 139{,}500.0)\right]$$

$$W_{PH} = 19{,}674{,}125^{\#} \ @\ \bar{X} = 52'$$

DETERMINE OVERTURNING RESISTANCE MOMENT:

$$\Sigma M_R = (244{,}462.5^{\#}\cdot 34') + (234{,}003\cdot 48') + (1{,}673{,}763\times 98') + (1{,}653{,}120^{\#}\cdot 140') + (1{,}344{,}000^{\#}\cdot 80') + (4{,}851{,}280^{\#}\cdot 30') + (5{,}594{,}400\cdot 67.67) + (298{,}340^{\#}\cdot 10.5') + (19{,}674{,}125^{\#}\cdot 52') + (1{,}080{,}000\cdot 2\cdot 80) + (24{,}907.5\cdot 162') + (16{,}693{,}560^{\#}\cdot 142.72) + (19{,}114{,}126.2\cdot \sin 45^{\circ}/140)$$

$$F.S._{OT} = \frac{\Sigma M_R}{\Sigma M_O} = \frac{6{,}524{,}368{,}177.55}{1{,}856{,}775{,}972.5}$$

$$F.S._{OT} = 3.50$$

W/O POWER GENERATION EQUIPMENT

$$F.S. = 3.5 > 3.0$$

VERY ADEQUATE W/O EQUIPMENT

Stability Analyses & Evaluations (Cont'd)

Powerhouse Factor of Safety Against Sliding

Weight of Components Reference Sheet 11

1. Bridge Section 244,462.5#
2. Buttresses #7 & #8 10,445,680.0#
3. Weight of PH w/o Equip. 19,674,125.0#
4. Weight of Sloping Arch 1,673,746.3#
5. Weight of Vertical Portion of Arch 234,003.0#
6. Weight of Arch Buttress 1,653,120.0#
7. Weight of Buttress Foundations 1,344,000.0#
8. Weight of Porch & Columns 298,340.0#
9. Weight of Water on Arch 16,693,560.0#

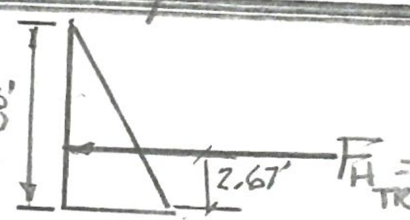
Total Weight of PH & Water 52,261,036.8#

10 See Page 12 →

11. Normal Uplift on Buttress Fdns 6,027,840#
12. Excess Tailrace Uplift 262,080#

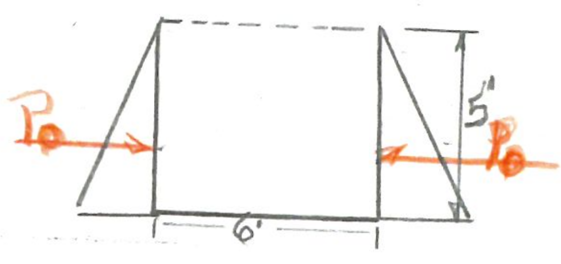
Total Uplift = 6,289,920.#

13. Tailrace Hydrostatic Resistance



$F_{H_{TR}} = 250\#/' \cdot 35' = 8,736\#$

14. Lateral "At-Rest" Friction Resistance



$K_0 = 1 - \sin\phi \quad \phi = 52°$

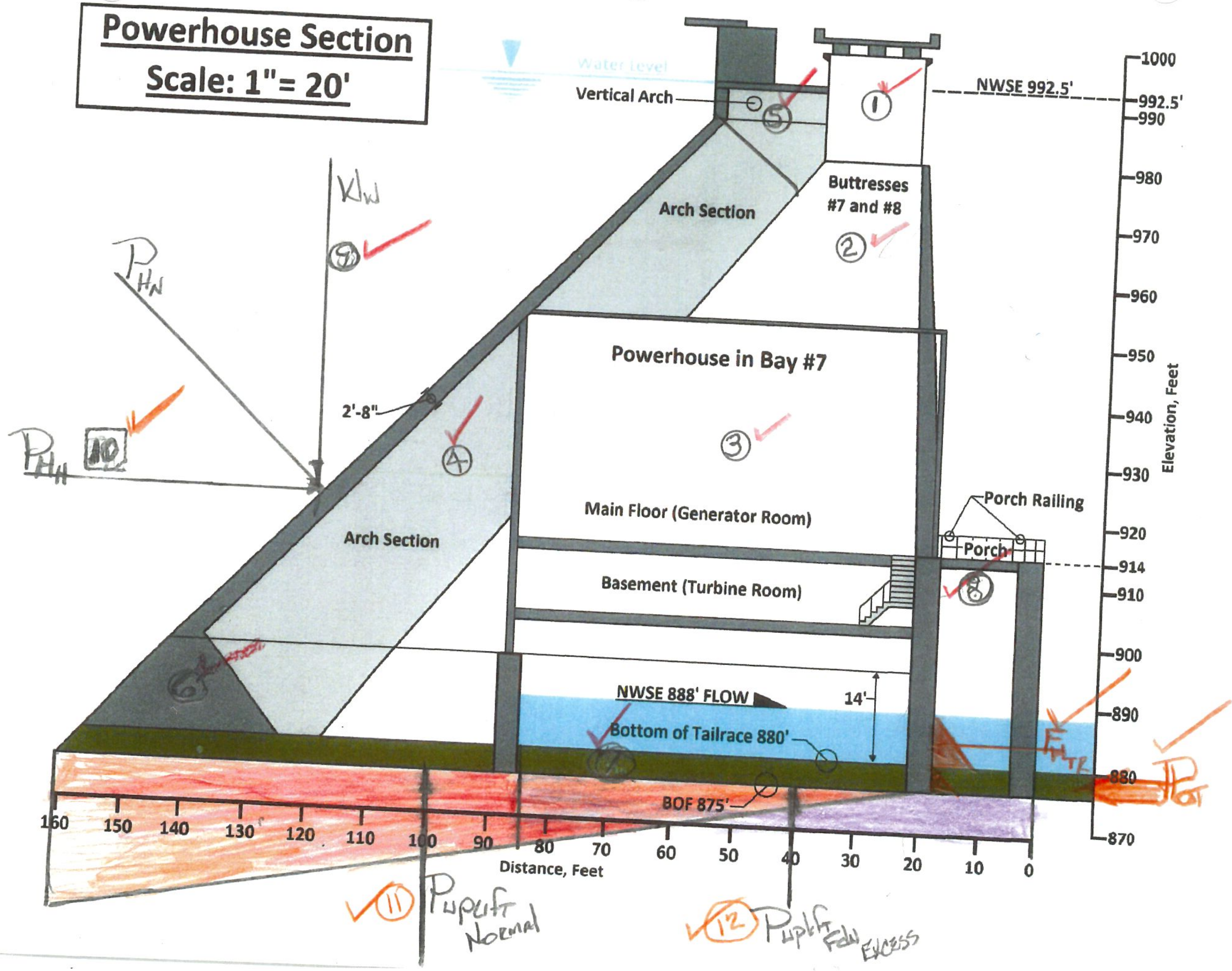
$K_0 = 0.21$

$P_{0_{TOTAL}} = 2 \cdot 135\,pcf \cdot 1/2 \cdot 21 \cdot 160'$

$P_{TOTAL} = 453,600\#$

Powerhouse Section

Scale: 1"= 20'



Stability Analyses and Evaluations (Cont'd)

Powerhouse Factor of Safety Against Sliding:

$$F.S._{PH\,Sliding} = \frac{\left[\Sigma W_{PH} - \Sigma F_{Uplift}\right] \tan\phi_{F\,\&\,Applicant} + \Sigma F_{Misc.\,Hort}}{\Sigma F_{Hort.\,Hydrostatic}}$$

$$F.S._{PH\,Sliding} = \frac{\left[52,261,036.0^{\#} - 6,289,920\right] \tan 52° + \boxed{462,336.0}}{19,114,128.2^{\#}}$$

$$F.S._{PH\,Sliding} = \frac{(45,971,116.8) \tan 52° + 462,336}{19,114,128.2^{\#}}$$

$$F.S._{PH\,Sliding} = \frac{58,840,346.3^{\#} + 462,336}{19,114,128.2}$$

$$F.S._{Sliding} = 3.10 > 3.0$$

OK

STABILITY ANALYSES & EVALUATIONS (CONT'D)

POWERHOUSE FACTOR of SAFETY EARTHQUAKE:

$$\epsilon = 0.10$$

$$F.S._{PH_{EARTHQUAKE}} = \frac{[52{,}261{,}036.8 - 6{,}289{,}920 \cdot 1.10] \tan 52^\circ + [462{,}336]}{19{,}114{,}128.2 \cdot (1+\epsilon)}$$

$$F.S._{PH_{EARTHQUAKE}} = \frac{58{,}497{,}609.2}{21{,}025{,}541.0}$$

$$\boxed{F.S._{PH\,EARTHQUAKE} = 2.78 >> 1.0}$$

VERY GOOD