Stability Analyses & Evaluations (Cont'd)

Buttress No. 9 in Bay No. 8:

Factors of Safety Under Normal Loading:

Allowable Shear Strength, $f_c = 71.55$ psi

Note: Use $f_c = 72$ psi

Reference Sheet 2

Observed Shear Crack Beginning At Contact of Arch Slab & Buttress

Reference Sheets 3 & 4

Normal Loading Factors of Safety:

Point 1: $F.S._{SHEAR} = \frac{f_{CALL}}{v_N} = \frac{0.72}{0.72} = 1.0$

Incipient Shear Failure (Just Beginning to Exist or Appear)

Point 2: $F.S._{SHEAR} = \frac{72 psi}{80 psi} = 0.9 < 1.00$

Imminent Shear Failure (Likely To Occur Without Delay or Warning = Impending Failure)

Point 3: $F.S._{SHEAR} = \frac{72 psi}{80 psi} = 0.9 < 1.00$

SHEET 2 OF 7

concrete

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Part IV-B.

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reinforce-

18,000 psi

30,000 psi

24,000 psi
20,000 psi

30,000 psi

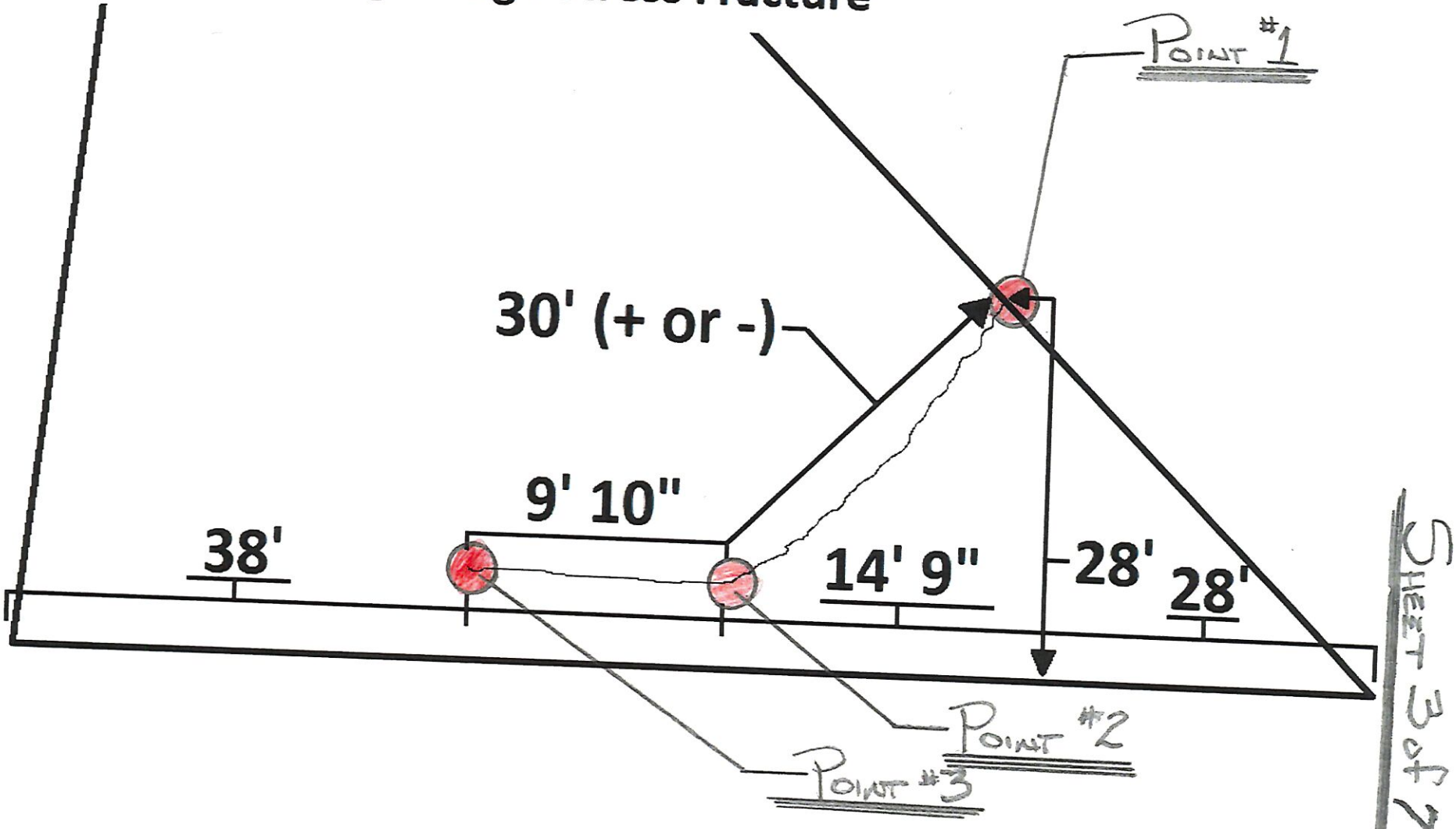
TABLE 1002(a)—ALLOWABLE STRESSES IN CONCRETE

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		$\frac{29{,}000}{w^{1.5}\,33\sqrt{f_c'}}$				
For concrete weighing 145 lb per cu ft (see Section 1102)	n	$f_c' = 2000$ psi, $w = 140$ pcf, 11.86	10	9	8	7
Flexure: f_c		$f_c' = 2000$ psi				
Extreme fiber stress in compression	f_c	$0.45f_c'$ 900 psi	1125	1350	1800	2250
Extreme fiber stress in tension in plain concrete footings and walls	f_c	71.55 psi, $1.6\sqrt{f_c'}$	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.

Buttress #9 in Bay #8

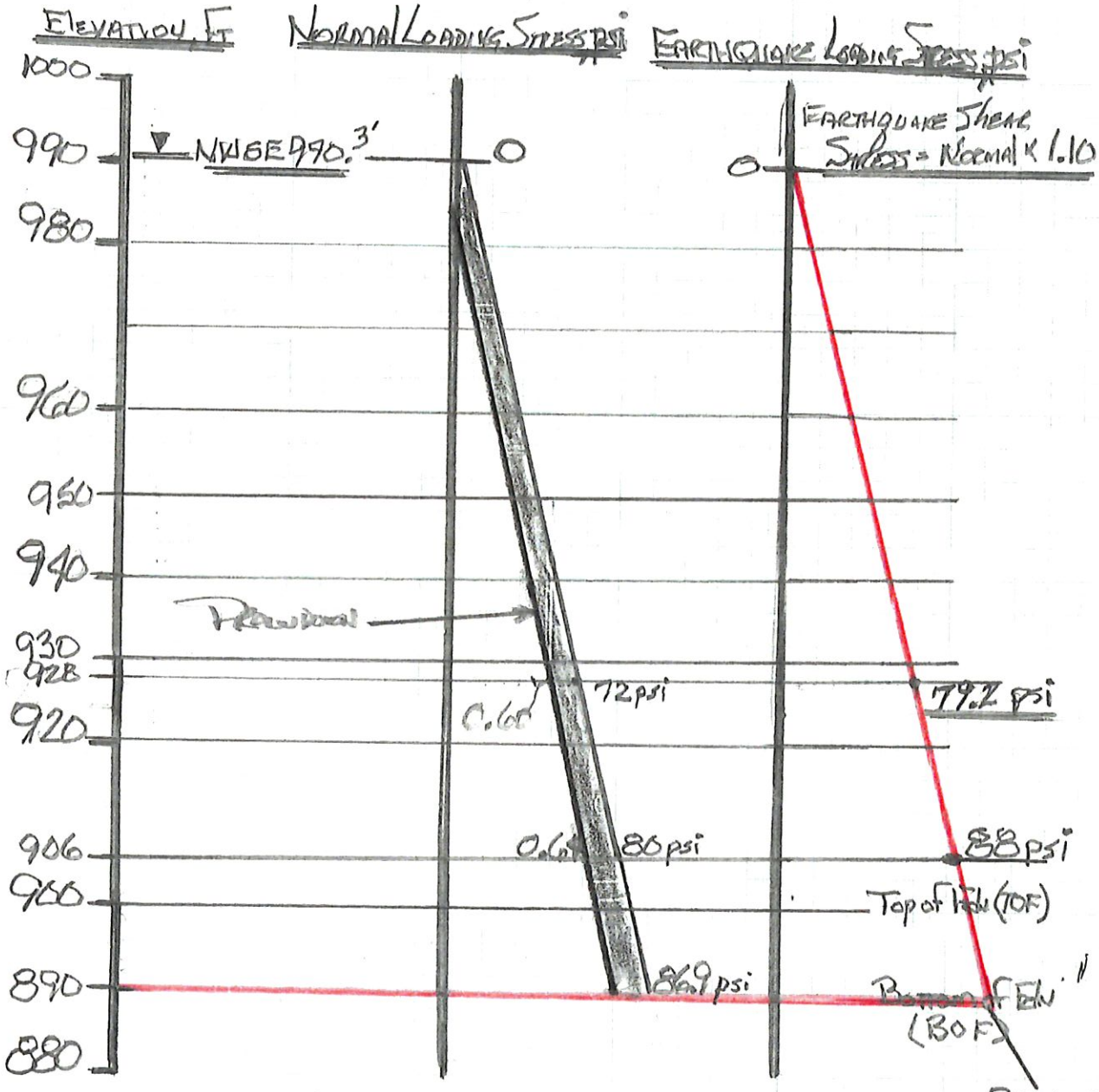
Image Showing a large Stress Fracture



Stress Distribution Vs Depth

Buttress No. 9 - Bay No. 8

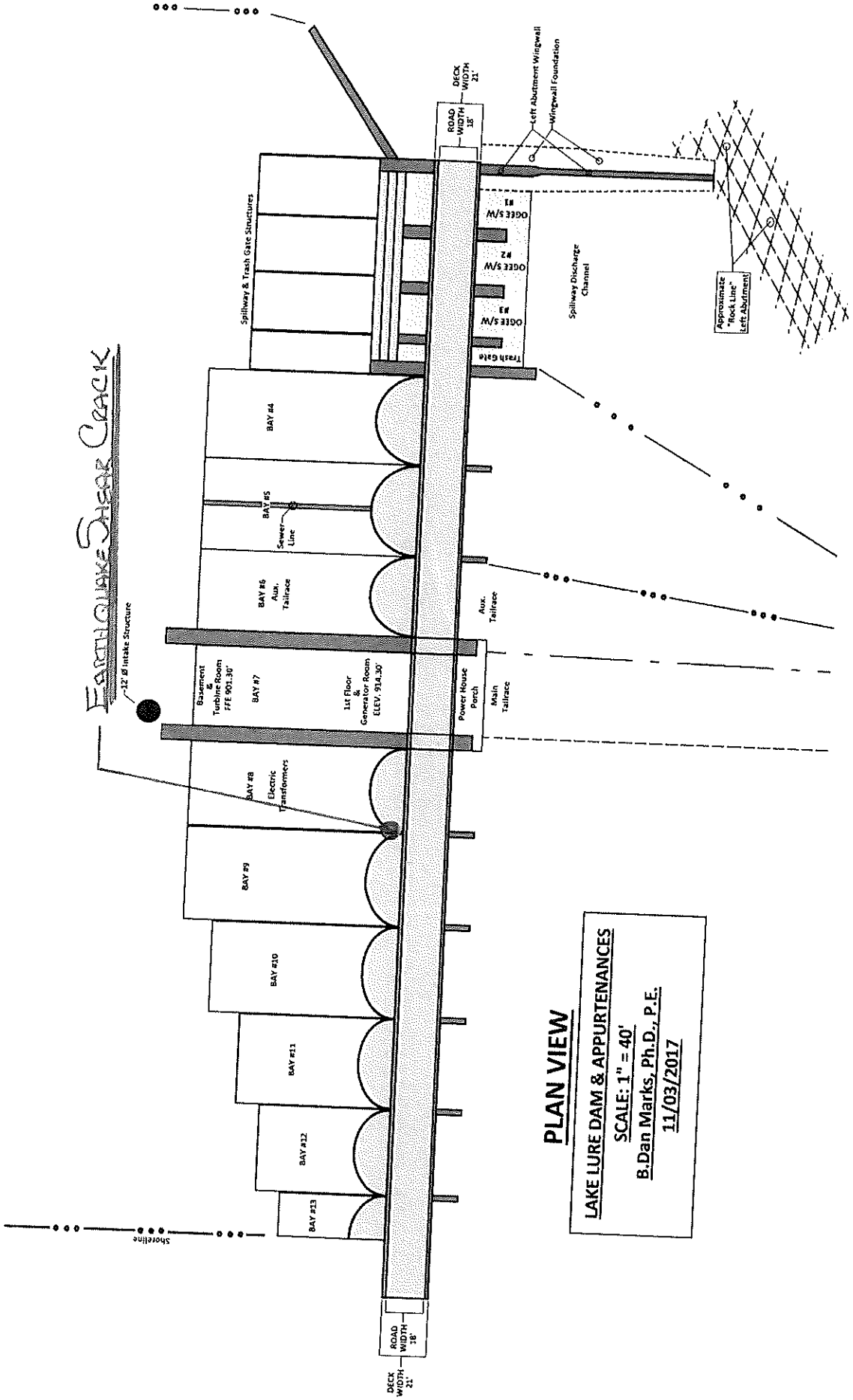
Scale: As Shown



$$\text{Shear Stress} = \frac{\text{Depth} \cdot \gamma_o}{\text{Width of Buttress}}$$

$$f_{c\,928.0'} = \frac{62.3' \cdot 62.4\ psf}{54'} = 71.99\ psi\ (72\ psi)$$

SHEET No. 5 of 2



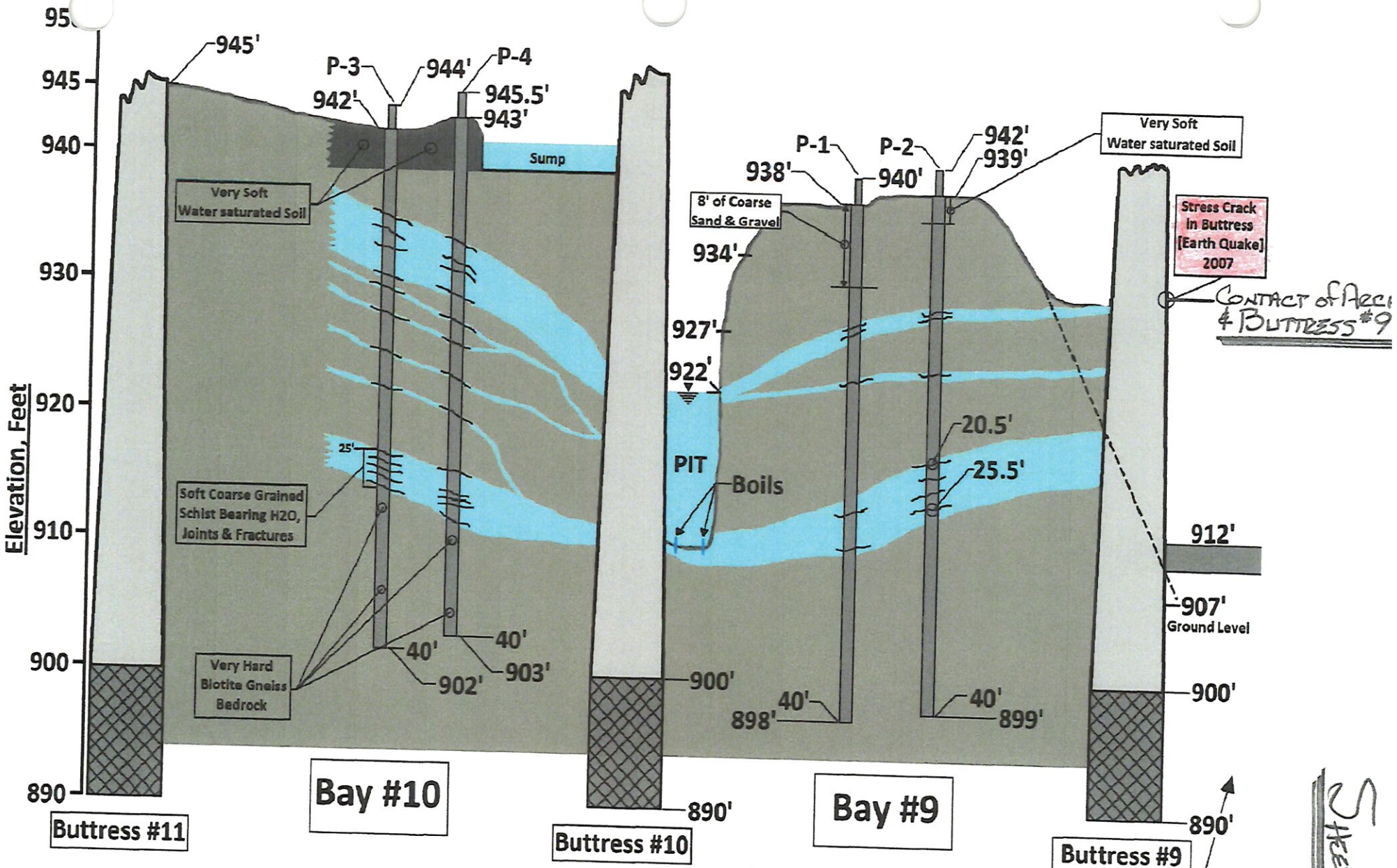
PLAN VIEW

LAKE LURE DAM & APPURTENANCES

SCALE: 1" = 40'

B.Dan Marks, Ph.D., P.E.

11/03/2017



Borings & Piezometer Installations

Scale: 1" = 10' (approx.)

Sheet No. 6 of 7

STABILITY ANALYSES & EVALUATIONS (CONT'D):

BUTTRESS NO. 9 IN BAY #8:

FACTORS OF SAFETY UNDER EARTHQUAKE LOADS

ALLOWABLE SHEAR STRESS, $f_c = 72$ psi

FACTORS OF SAFETY DURING EARTHQUAKE

REFERENCE SHEETS #4 THRU #6

EARTHQUAKE FACTORS OF SAFETY:

POINT #1: $F.S._{EQ\,SHEAR} = \frac{f_{ALL.}}{V_{EQ}} = \frac{0.72}{0.792}$

$F.S. = 0.91 < 1.0$

STRUCTURAL STABILITY TRANSFER FROM POWERHOUSE

POINTS #2 & #3:

DRAWDOWN CONDITIONS: $F.S._{EQ\,SHEAR} = \frac{0.72}{0.88} = 0.82$

POINT #1: $F.S. = \frac{0.72}{0.60}$

$F.S. = 1.20$

POST EQ $F.S. = \frac{0.72}{0.80} = 0.90$

POINTS #2 & #3: $F.S. = \frac{0.72}{0.64}$

$F.S. = 1.13$

IMPENDING FAILURE

MARKS ENTERPRISES OF NC, PLLC

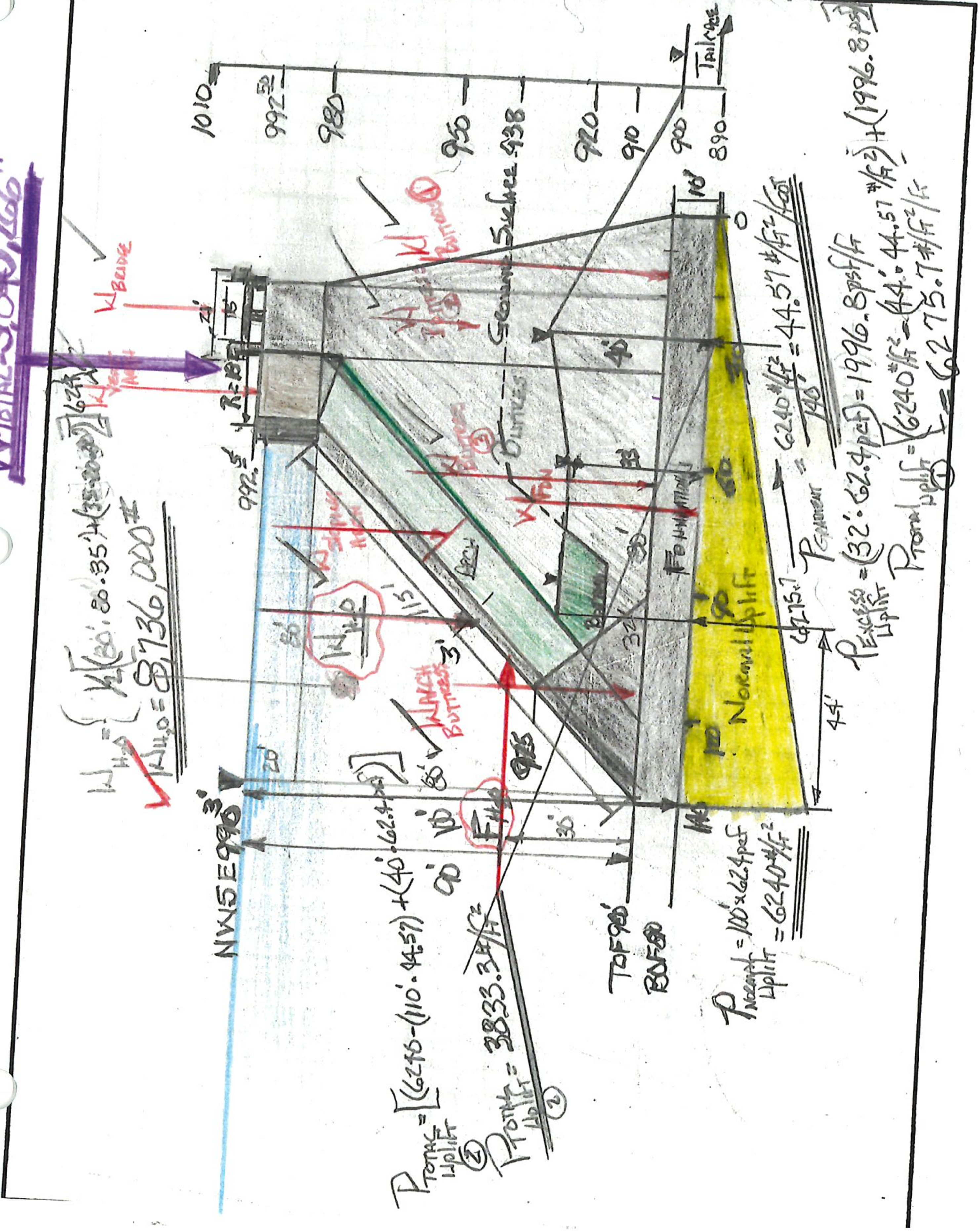
BY: BDM DATE: 01-19-2018

PROJECT: Phase II Lake Lure Dam ...

SHEET No. 1 of 5

PROJECT No. ME-16-006

Stability Analyses & Evaluations (Cont'd)



STABILITY ANALYSES & EVALUATIONS (CONT'D)

NORMAL LOADING FACTORS of SAFETY:

BUTTRESS No. 9

REFERENCE SHEET No. 3

DETERMINATION of WEIGHTS; LOADS & MOMENTS

BUTTRESS No. 9 WEIGHTS:

① WEIGHT of 1/2 SECTION of BRIDGE SPAN:

REFERENCE POWERHOUSE CALCULATIONS:

$W_{1/2\ BRIDGE\ SPAN} = 1/2 \cdot 244{,}462.5\ \#$

$W_{BRIDGE} = 122{,}231.25\ \#$

② WEIGHT of 1/2 WEIGHT of VERTICAL ARCH SPAN:

REFERENCE POWERHOUSE CALCULATIONS

$W_{VERT\ ARCH} = 1/2 \cdot 234{,}003 = 117{,}001.5\ \#$

③ WEIGHT of 1/2 WEIGHT of SLOPING ARCH SECTION:

$W_{SLOPING\ ARCH\ SECTION} = 836{,}873.2\ \#$

④ WEIGHT of 1/2 WEIGHT of SLOPING ARCH BUTRESS:

$W_{SLOPING\ ARCH\ BUTRESS\ SEGMENT} = 826{,}560\ \#$

⑤ WEIGHT of BUTTRESS FOUNDATION:

$W_{FDN} = (140' \times 10' \times 6') \cdot 140\ pcf = 1{,}176{,}000\ \#$

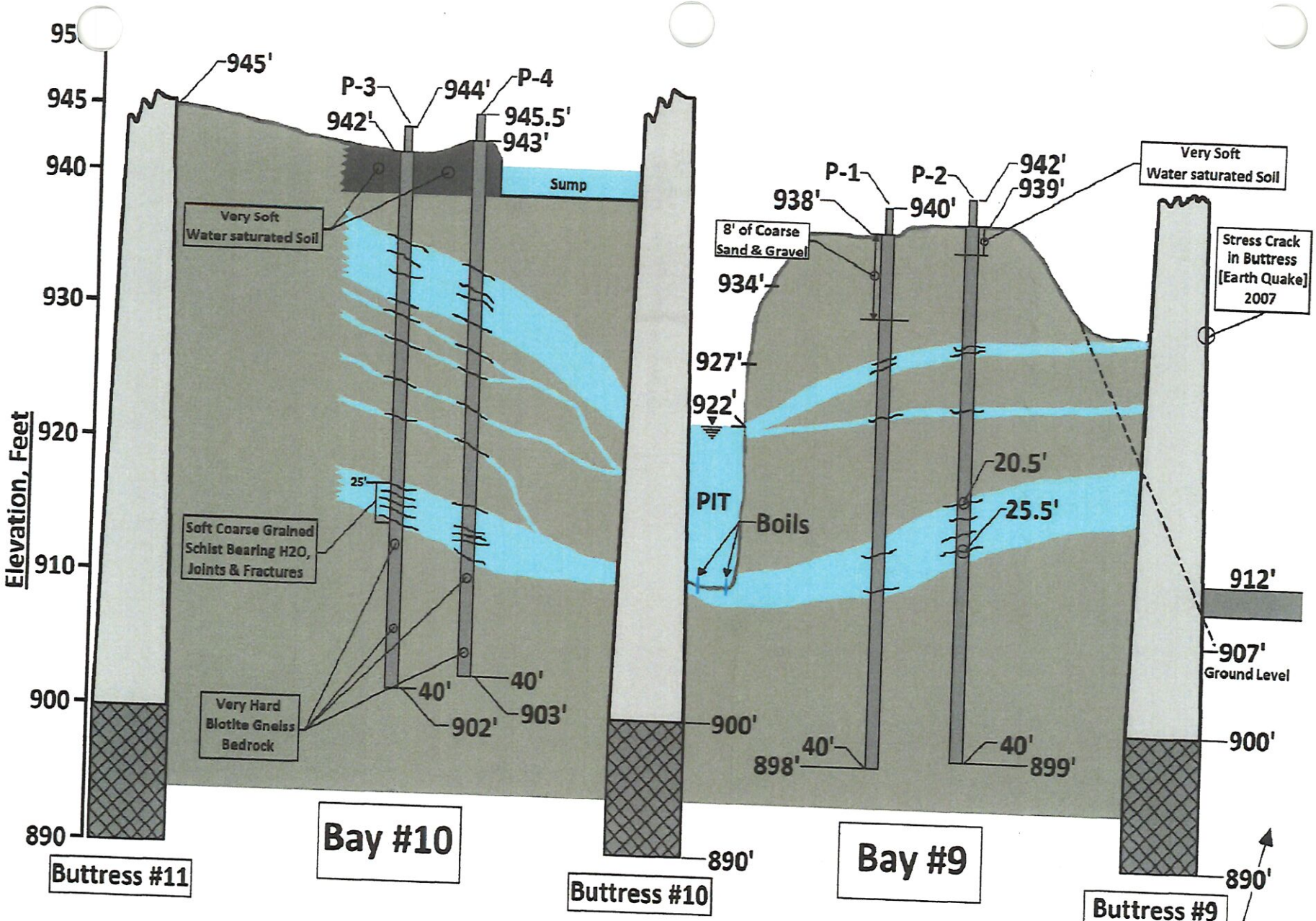
⑥ WEIGHT of BUTTRESS #9 $= [(1/2 \cdot 20' \cdot 80') + (18' \cdot 80') + (1/2 \cdot 80' \cdot 80')] \cdot 140\ pcf$

$W_{BUTTRESS\ \#9} = (800 + 1440 + 3200) \cdot 140\ pcf$

$W_{BUTTRESS\ \#9} = 761{,}600\ \#$

TOTAL WEIGHT of BUTTRESS #9 $= 3{,}840{,}265.95\ \#$

USE $W_{BUTTRESS\ \#9} = 3{,}840{,}266\ \#$



Borings & Piezometer Installations

Scale: 1" = 10' (approx.)

SHEET No. 3 of 5

MARKS ENTERPRISES OF NC, PLLC
1 Palatka Street Arden, North Carolina 28704
DAM AND GEOTECHNICAL ENGINEERING AND CONSULTING

BUTTRESS NO. 10 FACTOR of SAFETY IMMEDIATELY AFTER BOUNCE:

$$F.S._{\text{SLIDING}}_{\text{NORMAL CONDITIONS}} = \frac{(W_{TOTAL} - U_{PLIFT\ TOTAL}) \tan \phi_f}{F_{HORT}}$$

$$F.S. = \frac{(12,576,266 - 5,528,856) \tan 52^\circ}{8,845,200}$$

$$F.S. = 1.02 \doteq 1.00 \quad [\text{INCIPIENT FAILURE}]$$

BUTTRESS NO. 10 FACTOR of SAFETY DURING EARTHQUAKE LOADING

$$F.S._{\text{SLIDING}}_{\text{EARTHQUAKE}} = \frac{[W_{TOTAL} - (1+E) U_{PLIFT\ TOTAL}]}{F_{HORT}(1+E)}$$

$$F.S._{\text{SLIDING EARTHQUAKE}} = \frac{[12,576,266 - 1.10(5,528,856)]}{8,845,200\ (1+10)}$$

$$F.S._{\text{SLIDING EARTHQUAKE}} = \frac{8,312,612.2}{9,729,720.0}$$

$$F.S._{\text{SLIDING EARTHQUAKE}} = 0.85 \quad \text{FAILURE!!!}$$

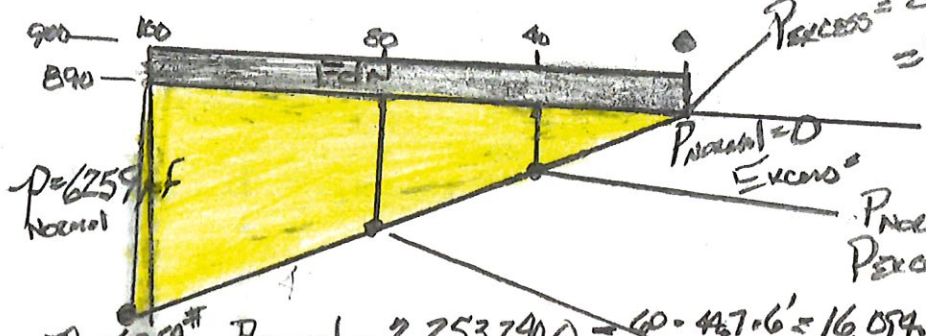
PHONE: 828-231-0598 Email: drbdan@bellsouth.net FAX: 828-687-2991

BUTTRESS No. 10 APPROXIMATELY ONE WEEK FOLLOWING BORING & PIEZOMETER INSTALLATION

TOTAL WEIGHT of BUTTRESS #10 = 12,576,266 #

TOTAL HYDROSTATIC LATERAL FORCE = 8,845,200 #

TOTAL UPLIFT AFTER 7 DAYS FOLLOWING DRILLING & INSTALLING PIEZOMETERS:



$P_{uplift\ TOTAL} = 3,554,581.1$ #

$$F.S. = \frac{(12,576,266 - 3,554,581.1)\tan 52°}{8,845,200}$$

$$F.S._{Normal\ after\ ONE\ WEEK} = \frac{11,547,666.7}{8,845,200}$$

$$F.S._{Normal\ after\ One\ Week} = 1.31$$

$$F.S._{EARTHQUAKE} = \frac{12,576,266 - (1.1)3554,246)\tan 52°}{(1.1)(8845,200}$$

$F.S._{EQ} = 1.14$

PRELIMINARY EVALUATION ANALYSES

EXAMINE FAILURE CONDITIONS OF BUTTRESS #9

NORMAL LOADING CONDITIONS FACTOR of SAFETY:

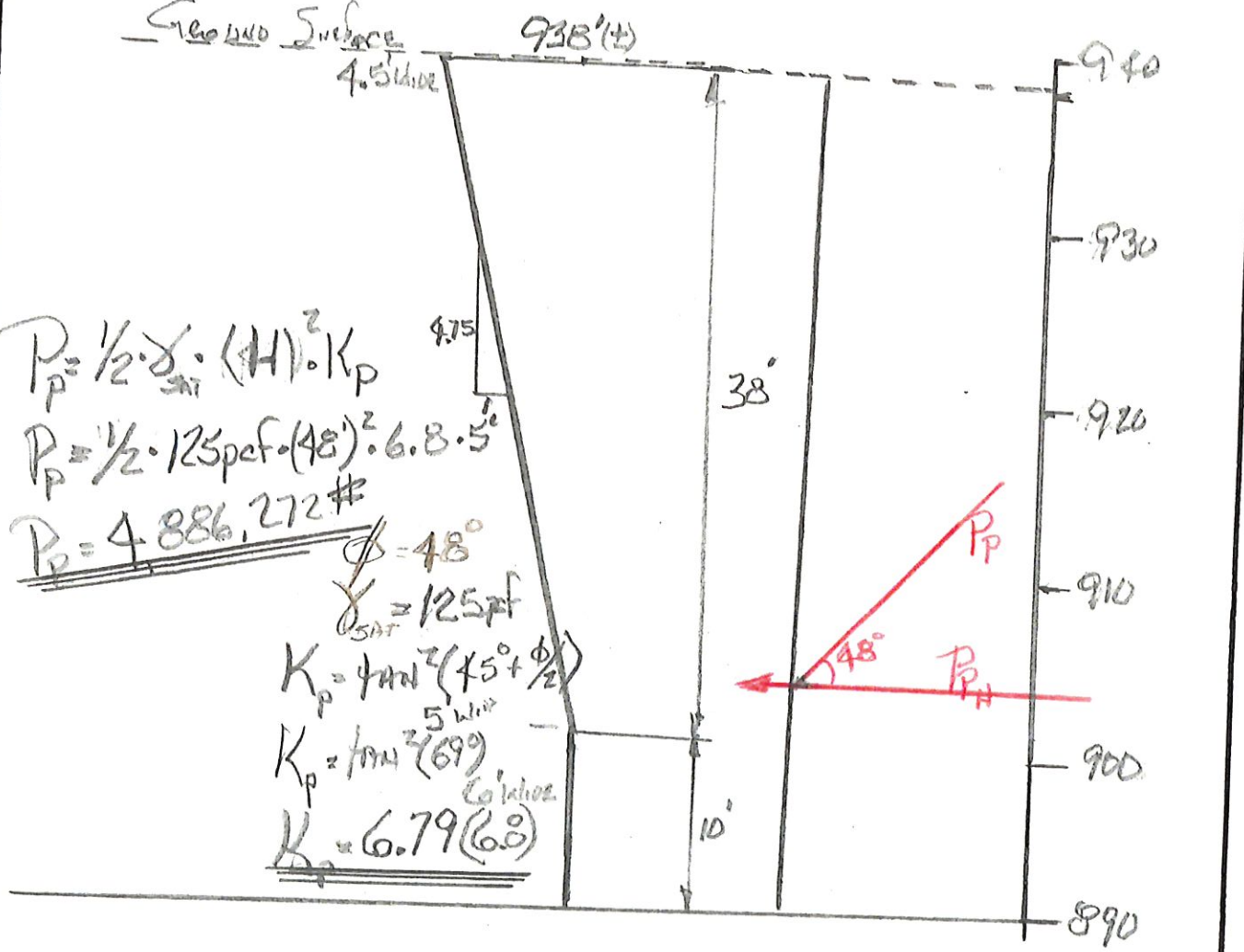
FACTORS of SAFETY W/O PASSIVE EARTH PRESSURE

TAN ϕ_S = TAN 52° = 1.28; F.S. = 1.32

TAN ϕ_S = TAN 45° = 1.00; F.S. = 1.03

PASSIVE EARTH PRESSURE @ D/S TOE of BUTTRESS:

8' IN 38'; 8/38 = 1'/4.75' 1" = 4.75"



$P_P = \frac{1}{2} \cdot \gamma_{SAT} \cdot (H)^2 \cdot K_p$

$P_P = \frac{1}{2} \cdot 125pcf \cdot (48')^2 \cdot 6.8 \cdot 5'$

$P_P = 4,886,272\#$

$\phi = 48°$

$\gamma_{SAT} = 125pcf$

$K_p = \tan^2(45° + \phi/2)$

$K_p = \tan^2(69°)$ 5 H:1V

$K_p = 6.79 (6.8)$ Co'ulver

Factor of Safety [Normal Loading] ≥ 3.0 Req'd

$$F.S. = \frac{(V_{total} - Uplift_{total}) \tan\phi_c + P_p}{F_H}$$

$$F.S. = \frac{(12,576,266^{\#} - 3,431,986.8^{\#}) \tan 48^{\circ} + 4,886,272^{\#}}{8,845,200^{\#}}$$

F.S. = 1.70 << 3.0

NOT GOOD

But Better Than 1.32

$P_p = \frac{1}{2} \gamma_{sat} \tan^2(45^{\circ} + \frac{\phi}{2})(45)^2 \cdot 5$

$P_p = 3,486,883.6$ If End of Buttress is in Rock &

$\phi_{effective} = 42^{\circ}$ & $\gamma_{SAT} = 120$ pcf

$$F.S. = \frac{(12,576,266 - 3431,986.8) \tan 42^{\circ} + 3,486,883.6}{8,845,200^{\#}}$$

F.S. = 1.33 << 3.0

NOT GOOD

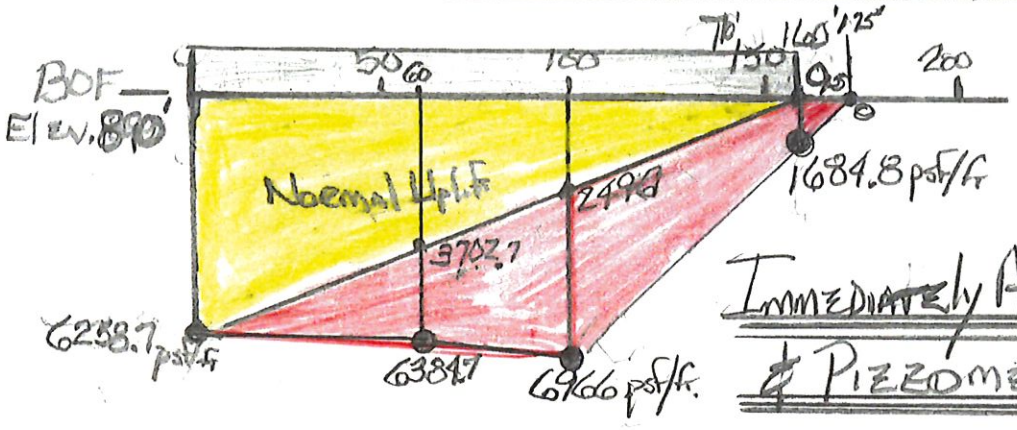
Even Worse - There is No Conservation w/ P_p If $\phi <$ About 48°

STABILITY ANALYSES & EVALUATIONS (CONT'D)

FACTOR of SAFETY AGAINST SLIDING FAILURE:

BUTTRESS No. 10 - NORMAL LOADING:

REFERENCE SHEETS No. 2 & 3



IMMEDIATELY AFTER DRILLING & PIEZOMETER INSTALLATION

NORMAL UPLIFT; $Uplift_{NORMAL} = \frac{1}{2} \cdot 6258.7\ psf/ft \cdot 160\ ft \cdot 6\ feet$

$Uplift_{NORMAL} = 3,004,176\ \#$

EXCESS UPLIFT; $Uplift_{EXCESS\ ①} = \frac{1}{2} \cdot (6966 - 2496) \cdot 100 \cdot 6'$

$Uplift_{EXCESS\ ①} = 1,341,000\ \#$

$Uplift_{EXCESS\ ②} = \left(\frac{4470 + 1684.8}{2}\right) 60' \cdot 6'$

$Uplift_{EXCESS\ ②} = 1,107,864\ \#$

$Uplift_{EXCESS\ ③} = \frac{1}{2} \cdot 1684.8 \cdot 15' \cdot 6'$

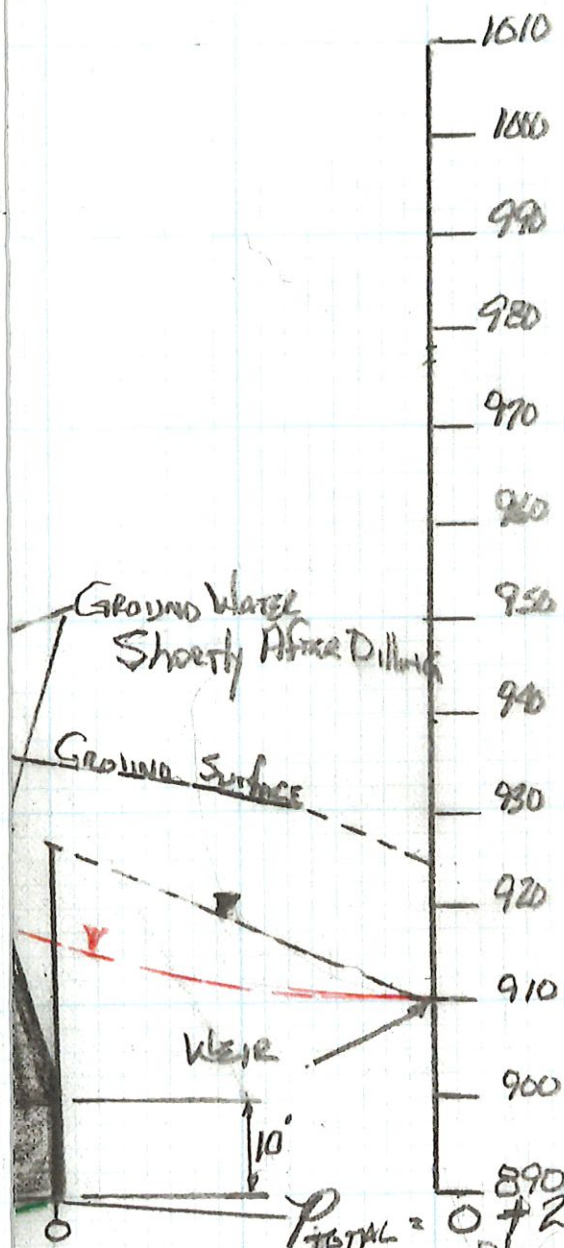
$Uplift_{EXCESS\ ③} = 75,816\ \#$

$Total\ Uplift = Uplift_{Normal} + Uplift_{Excess\ ①} + Uplift_{Excess\ ②} + Uplift_{Excess\ ③}$

$Total\ Uplift = 3,004,176 + [1,341,000 + 1,107,864 + 75,816]$

$Total\ Uplift = 3,004,176 + 2524,680 =$

$Total\ Uplift = 5,528,856\ \#$



$P_{TOTAL} = 0 + 27' \cdot 62.4 = 1681.8$

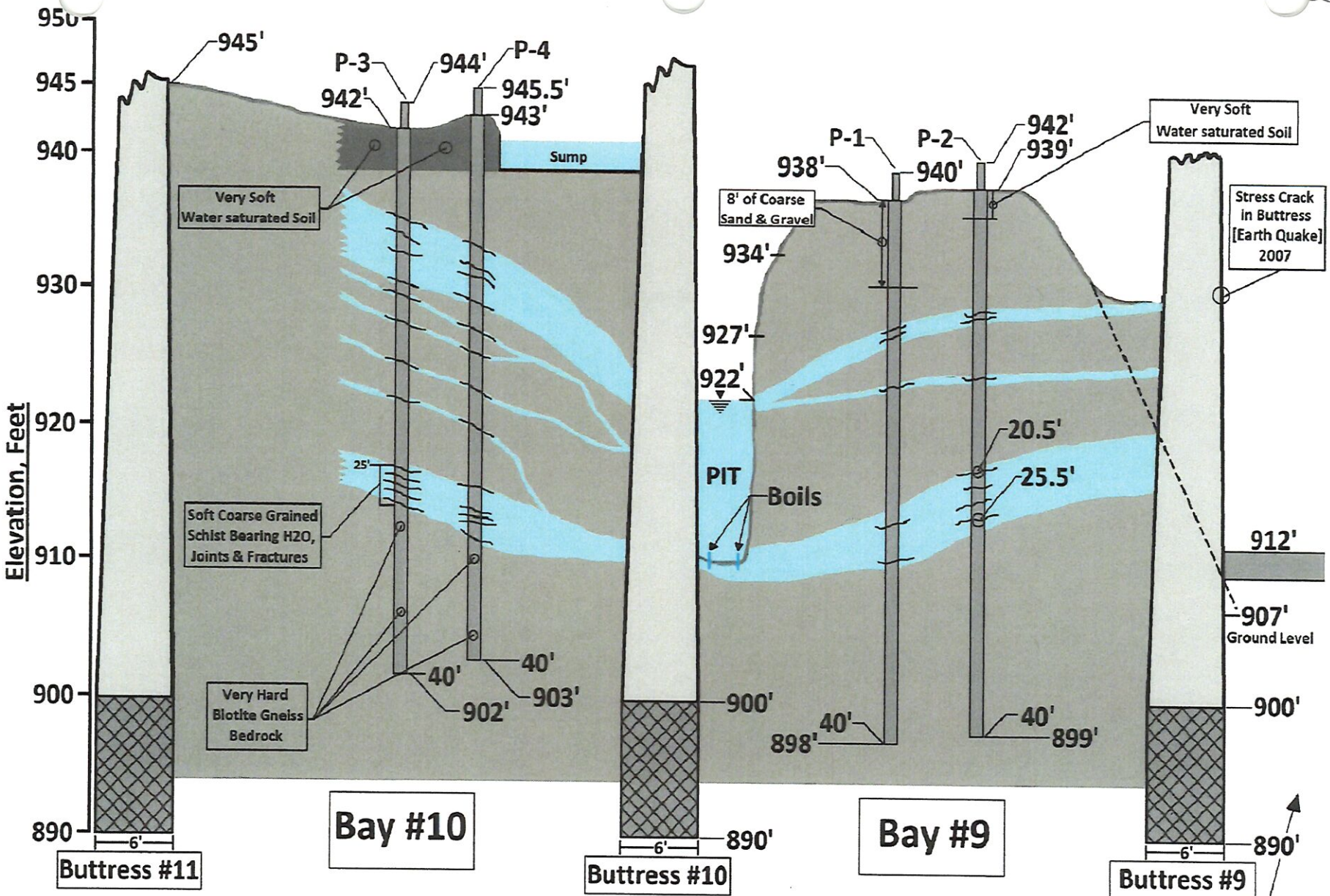
$P_{Uplift} = 100' \cdot 44.7 = 4470.0$ psf/ft

$P_{EXCESS} = 40.0' \cdot 62.4$ psf $= 2496$ #/ft

$P_{Uplift} = 6384.7$ psf

P_{Total} 6966 psf/ft

11



Borings & Piezometer Installations

Scale: 1" = 10' (approx.)

Stability Analyses & Evaluations (Cont'd)

Weight of H_2O on 1/2 of Arch Slab:

Reference Sheet No. 1:

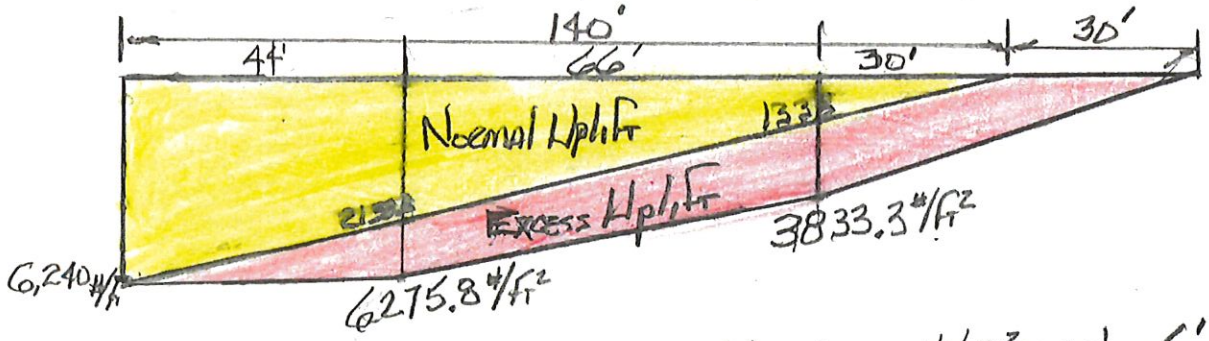
$$W_{H_2O} = 8{,}736{,}000\ \#$$

$$F_{H_2O\ Horz.} = \tfrac{1}{2}\left[\tfrac{1}{2}\cdot\gamma_0\cdot H^2\right] = 0.5\left[0.5\cdot 62.4\ pcf\cdot (90')^2\right]\cdot 35'$$

$$F_{H_2O\ Horz.} = 8{,}845{,}200\ \#$$

Factor of Safety Against Sliding (Normal Loading):

Resisting Force, $F_R = (W - Uplift)\tan\phi_F$



Normal Uplift, $W_{PLIFT_{Norm}} = \tfrac{1}{2}\cdot 6240\ \#/ft^2\cdot 140'\cdot 6'$

$$W_{PLIFT_{Norm}} = 2{,}620{,}800\ \#$$

Excess Uplift, $W_{PLIFT_{EXCESS}} = \left\{\left[\left(\tfrac{1}{2}\cdot 41\tfrac{1}{2}.5\cdot 44'\right) + \left(\tfrac{(41\tfrac{1}{2}.5 + 2495.3)}{2}\cdot 66'\right)\right]\#\right\}6'$

$$W_{PLIFT_{EXCESS}} = 811{,}186.8\ \#$$

Total Uplift $= W_{PLIFT_{Norm}} + W_{PLIFT_{EXCESS}}$

$= 2{,}620{,}800\ \# + 811{,}186.8\ \#$

$= 3{,}431{,}986.8\ \#$

STABILITY ANALYSES & EVALUATIONS (CONT'D)

DETERMINE FACTOR of SAFETY AGAINST SLIDING:

$$F.S._{SLIDING\ BUTTRESS} = \frac{(W_{TOTAL} - U_{PLIFT\ TOTAL}) \tan\phi_f}{F_{HORT}}$$

$$F.S._{SLIDING\ BUTTRESS} = \frac{[12,576,266 - 3,431,986.8^{\#}] \tan 52^{\circ}}{8,845,200^{\#}}$$

$$F.S._{SLIDING} = 1.32 < < < 3.0$$

VERY INADEQUATE

DETERMINE FACTOR of SAFETY FOR EARTHQUAKE LOADING CONDITION: EXTREME LOADING

$$F.S._{EARTHQUAKE} = \frac{(W_{TOTAL} - U_{PLIFT} \cdot 1+\epsilon) \tan\phi_f}{(1+\epsilon) F_{HORT}}$$

$$F.S._{EARTHQUAKE} = \frac{(12,576,266^{\#} - (1.10) \cdot 3,431,986.3^{\#}) \tan 52^{\circ}}{(1.10) 8,845,200^{\#}}$$

$$F.S._{EARTHQUAKE} = 1.16 > 1.0$$

INCIPIENT

Stability Analyses & Evaluations (Cont'd)

Stability Analyses and Evaluations of Buttress No. 11 on the Right Abutment Side of Bay No. 10 By Interpretation of Mathematical Calculations From the Stability Analyses Performed For Evaluations of Buttresses No. 9 & 10 In Bays No. 9 & 10, Respectfully:

FACTS:

1. The Physical Dimensions & Characteristics of Buttress No. 11 are virtually identical to those of Both Buttresses No. 9 & 10 within the Evaluation Limits of Geotechnical Engineering Analyses.
2. As a result of Conditions Expressed In Item #1 Above, the Total Weight of Buttress No. 11 and the Normal Uplift Pressures Acting on Buttress No. 11 are the same as those for Buttresses No. 9 and No. 10 within the Limits of Geotechnical Engineering Evaluations. Namely,

Total Weight ≈ 3,840,250 #

Total Normal Uplift ≈ 2,620,800 #

Total Excess Uplift ≈ 2,524,680 #

Total Uplift @ Time of Drilling ≈ 528,900 #

F.S. Normal Loading ≈ 1.34 After Partial Drainage — Imminent Failure

F.S. Thermal Loading ≈ 1.02 ≈ 1.0 — Incipient Failure

End of Stability Analyses