APPENDIX A

COMPUTER PROGRAM USER'S GUIDE

Title

Bulkhead Design for Anchored or Cantilevered Walls in Sand or Clay Subgrades.

Purpose

The purpose of this computer program is to determine the depth of penetration of bulkhead sheet-piles, determine the tie-rod load per unit length of wall, compute the maximum bending moment, and select the appropriate USS steel sheet pile and timber sheet pile. The design method is Free Earth Support as modified by Rowe.

Input

Cards 1 through 30 comprise moment and tie-rod reduction factors and USS steel sheet pile design data. These data cards are provided with the program.

Control Cards: 2 each. Must be right-justified.

Card 1
1-2 NP - Number of designs to be run.

Card 2
1-2 KC - Type of wall to be designed.
KC = 0: Anchored wall only.
KC = 1: Cantilevered wall only.
KC = 2: Both types will be designed.

3-4 N - Number of soil layers in the site.
N must be 2 or greater.

Soil Parameter Cards: 1 card for each soil layer. English units. Not right or left-justified, but a decimal is required.
1-10 PHI - Angle of internal friction.
11-20 GAMMA - Total unit weight (lb/ft$^3$).
21-30 C - Cohesion (#/ft$^2$). Must be zero if $\phi \neq 0$.

**Site Geometry Cards:** 2 cards

Card 1
1-10 BOMEGA - Angle of backfill slope.
11-20 DOMEGA - Angle of dredge slope.

Card 2
1-10 H - Free standing wall height (ft).
11-20 HW - Height of water above dredge level (DL).
   This is the low water level.
21-30 HHW - Height of tie-rod above DL.
31-40 T1 - Distance from top of wall to 2nd soil layer.
41-50 T2 - Distance from top of wall to 3rd soil layer.
51-60 T3 - Distance from top of wall to 4th soil layer.

**Surcharge Cards:** 1 card

Card 1
1-10 QS - Uniformly distributed load (lb/ft$^2$).
11-20 QL - Line load (lb/ft).
21-30 QP - Point load (lb).
31-40 X - Horizontal distance from wall to load (for QL and QP only).

**Explanation**

Most sites can be approximated using 3 layers: the first layer consisting of moist (not saturated) soil between the top of the wall and the water level; the second layer extending to the DL; and the third layer extending beyond. Input of $T3 = 50$ ft is a good value since any distance beyond the depth of penetration will be neglected.

The field width for each soil layer is 10 spaces. Each additional soil layer may be input utilizing this width, e.g., $T4$ would be input using columns 61-70.

Values of zero must be input on soil parameter, site geometry and surcharge cards with a decimal point.

The use of cohesion parameters above the DL will result in un-conservative designs. An explanation is contained in Chapter 3. Long term strength parameters should be used instead.
FILE: WALL    RPT53IN   8       CCMALL VIA/P SUBSET CMS LEVEL 108

DIMZ(1)=10132131313          C=131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131313131
FILE: WALL FORTRAN 4

53 CONTINUE
IF (XH < 0) GO TO 66
XH = -XH
X = XH
R = R + EL
IF (L < X) GO TO 40
IF (L > XH) GO TO 66

56 CONTINUE
R = R + EL
IF (L < XH) GO TO 40
IF (L > X) GO TO 66

76 FORMAT (Y35,E15.6) PULL = *,F9.5, 1/E3,FT)
1022 FORMAT (E15.6)
RETURN
END

SUBROUTINE DECONOM(Z, CT, CS, FT, PS, K, N, H, L, C, M, EL, H, Y)

SUBROUTINE TO FIND LOC. OF ZERO SHEAR AND COMPUTE MAXIMUM
MOMENT AT THAT POINT

DIMENSION Z(10), CT(7), CS(10), FT(11), PS(10), K(10), C(10)

CALL DLK, K, H, Z

GND = 0
DO 41 I = 1, N
VW = F(I) * P(I)
DO 41 = 1, 11
IF (VW < Z(I)) Z(I) = Z(I) + P(I)
41 CONTINUE

27 CONTINUE
IF (Y < CT(I)) CT(I) = CT(I) + P(I)
DO 41 = 1, 7
IF (Y < CS(I)) CS(I) = CS(I) + P(I)
41 CONTINUE

30 CONTINUE
IF (X < 0) X = 0
X = X - X
R = R - EL
IF (L < X) GO TO 40
IF (L > 0) GO TO 66

FILE: WALL FORTRAN 4

53 CONTINUE
IF (XH < 0) GO TO 66
XH = -XH
X = XH
R = R + EL
IF (L < X) GO TO 40
IF (L > XH) GO TO 66

56 CONTINUE
R = R + EL
IF (L < XH) GO TO 40
IF (L > X) GO TO 66

76 FORMAT (Y35,E15.6) PULL = *,F9.5, 1/E3,FT)
1022 FORMAT (E15.6)
RETURN
END

SUBROUTINE DECONOM(Z, CT, CS, FT, PS, K, N, H, L, C, M, EL, H, Y)

SUBROUTINE TO FIND LOC. OF ZERO SHEAR AND COMPUTE MAXIMUM
MOMENT AT THAT POINT

DIMENSION Z(10), CT(7), CS(10), FT(11), PS(10), K(10), C(10)

CALL DLK, K, H, Z

GND = 0
DO 41 I = 1, N
VW = F(I) * P(I)
DO 41 = 1, 11
IF (VW < Z(I)) Z(I) = Z(I) + P(I)
41 CONTINUE

27 CONTINUE
IF (Y < CT(I)) CT(I) = CT(I) + P(I)
DO 41 = 1, 7
IF (Y < CS(I)) CS(I) = CS(I) + P(I)
41 CONTINUE

30 CONTINUE
IF (X < 0) X = 0
X = X - X
R = R - EL
IF (L < X) GO TO 40
IF (L > 0) GO TO 66
FILE: WALL

CONTINUE

IF (PT(N) = 20.0 AND RS(N) = 99.0) X = X
IF (PT(N) = 29.0 AND RS(N) = 99.0) X = X
M = M + 1
MON = MON + FIM + FIM

65 CONTINUE

66 CONTINUE

44 CONTINUE

WRITE (1, 135) X, FNM

RETURN

SURFOUT: IF (MON > PHI, FAC = BET, S2, PULL, ALPHA, Beta, ZT + ST + KL + FP, IXL, 1310)
CAD = 2.0 (2.0, 40)

C

DOUBLE PRECISION SLOPE, YINT, A(SCI), B(SCI), SCI
DIMENSION FAC(10), BET(10), S2(10), P2(10)
DIMENSION PHI(10), L(MAX), R(MAX), ALIAS N(10), M02(10, 10)

CALL FAC, S2, P2, PHI, ZT, KL, FP
CALL CLAY, FAC, ALPHA, Beta, ZT, PULL, PHI, FP, IXL, 1310
CALL TIE, FAC, ALIAS, N, M02, PHI, FP, IXL, 1310
CALL SURF, FAC, ALPHA, TIE, TO, PHI, FP, IXL, 1310
FILE: WALL

FORTRAN A

CONTINUE

DO 10 K

CONTINUE

CONTINUE
FILE: WALL  F77TRAN: A  CCNELL H/WCP SUBSET CMS LEVEL 19A

150 IF(CL.XX) T5(E)=T5(E) VAL=6620
151 IF(CL.XX) T5(E)=T5(E) VAL=6630
152 XI=1 VAL=6640
153 X2=1 VAL=6650
154 Y1=T5(I) VAL=6660
155 Y2=T5(J) VAL=6670
156 Y3=T5(K) VAL=6680
157 Y4=T5(I) VAL=6690
158 T5:E(I) VAL=6700
159 T5:E(I) VAL=6710
160 T5:E(I) VAL=6720
161 IF(KK.EQ.10 AND T5(EK).GE.T5(EK)) T5M=7126 VAL=6730
162 IF(KK.EQ.20 AND T5(EK).GE.T5(EK)) XN=26 VAL=6740
163 IF(KK.EQ.10 AND T5(EK).GE.T5(EK)) GO TO 79 VAL=6750
164 IF(KP.LT.XI.OR.KP.GT.X2) GO TO 73 VAL=6760
165 TAU=TP VAL=6770
166 GO TO 74 VAL=6780
167 73 CONTINUE VAL=6790
168 74 CONTINUE VAL=6800
169 IF(KK.EQ.10 AND K2.EQ.2) PCE=1-XF=15 VAL=6810
170 CONTINUE VAL=6820
171 IF(KP.EQ.10 AND K2.EQ.2) TAU=TAUVAL MAX
172 IF(KP.EQ.10 AND K2.EQ.2) GO TO 19 VAL=6830
173 WRITE(11,11) R(T3),T3(I),T3(J),T3(K),I1(I)
174 WRITE(11,11) TAU VAL=6840
175 WRITE(11,11) XP VAL=6850
176 WRITE(11,11) XIII VAL=6860
177 WRITE(11,11) X(1) VAL=6870
178 WRITE(11,11) X(2) VAL=6880
179 WRITE(11,11) X(3) VAL=6890
180 WRITE(11,11) X(4) VAL=6900
181 WRITE(11,11) X(5) VAL=6910
182 CHEMICAL ENERGY = YIELD POINT STRESS X 3+5
183 IF(KP.EQ.1) ZMON(/CA*.65)
184 IF(KP.EQ.1) ZMON(/CA*.65) VAL=6920
185 IF(KP.EQ.1) ZMON(/CA*.65) VAL=6930
186 IF(KP.EQ.1) ZMON(/CA*.65) VAL=6940
187 IF(KP.EQ.1) ZMON(/CA*.65) VAL=6950
188 IF(KP.EQ.1) ZMON(/CA*.65) VAL=6960
189 IF(KP.EQ.1) ZMON(/CA*.65) VAL=6970
190 IF(KP.EQ.1) ZMON(/CA*.65) VAL=6980
191 IF(KP.EQ.1) ZMON(/CA*.65) VAL=6990
192 IF(KP.EQ.1) ZMON(/CA*.65) VAL=7000
193 IF(KP.EQ.1) ZMON(/CA*.65) VAL=7010
194 IF(KP.EQ.1) ZMON(/CA*.65) VAL=7020
195 IF(KP.EQ.1) ZMON(/CA*.65) VAL=7030
196 IF(KP.EQ.1) ZMON(/CA*.65) VAL=7040
197 IF(KP.EQ.1) ZMON(/CA*.65) VAL=7050
198 IF(KP.EQ.1) ZMON(/CA*.65) VAL=7060
199 CONTINUE VAL=7070
200 CONTINUE VAL=7080
201 IF(KP.EQ.1) I=1 VAL=7090
202 IF(KP.EQ.1) I=1 VAL=7100
203 IF(KP.EQ.1) I=1 VAL=7110
204 IF(KP.EQ.1) I=1 VAL=7120
205 IF(KP.EQ.1) I=1 VAL=7130
206 CONTINUE VAL=7140
207 CONTINUE VAL=7150
FILE: HALL

C
C PERFORM REGRESSION ANALYSIS ON NAT. LOG. OF DATA POINTS
C USE GAUSSIAN ELIMINATION
C
DO 2 I=1,N
X=LOG(A(I))
Y=LOG(B(I))
SUMX=SUMX+X
SUMY=SUMY+Y
SUMX2=SUMX2+X*X
SUMXY=SUMXY+X*Y
2 CONTINUE
N=SUMX2/2
XBAR=SUMX/N
YBAR=SUMY/N

2 CONTINUE
S2=SUMXY-XY*P
S2=SUMX2-M*SUMX2
S2=SUMY2-M*SUMY2
S2=S2/M
S=SQRT(S2)

FORMAT(F9.1,CORP)

S Format of LOG-LOG CURVE = POWER OF DESIRED FUNCTION
S The Y-INT. OF THE LOG-LOG CURVE RATES AS A POWER OF NAT. EXP.

S GIVES THE COEFF. OF DESIRED FUNCTION

DO 4 I=1,N
C(I)=XBAR**I
4 CONTINUE

FORMAT(F9.1,CORP)

WRITE(11,5)
WRITE(11,6)

5 FORMAT(T9,F8.3)

WRITE(11,7)
WRITE(11,8)

7 FORMAT(T9,F8.3)

WRITE(11,9)
WRITE(11,10)

9 FORMAT(T9,F8.3)

WRITE(11,11)
WRITE(11,12)

11 FORMAT(T9,F8.3)

12 FORMAT(T9,F8.3)

13 FORMAT(T9,F8.3)

14 FORMAT(T9,F8.3)

RETURN

END

SUBROUTINE POI(X1,X2,Y1,Y2,T1,T2,XP,YP)

SUBROUTINE TO FIND POINT OF INTERSECTION OF TWO LINES

Y1-Y2)/(X2-X1)
Y1+1=K1*X1+1
T1=Y1+1/(Y2-X1)
T2=Y1+1/(Y2-X1)

X1+1+T2
FILE: HALL_22T7411.A

CC: HALL_24/3P SUBSET 1:2 LEVEL 18

DEF: (FICL+K) = FICL+1 + FICL+K

DEF: (FICL+K) = FICL+1 + FICL+K

R = RH((N-1)

R = 4/(P1-P1)

P = (C-0)+P

TOTAL = TOTAL

T1. CONTINUE

RETURN

END
APPENDIX C

SAMPLE OUTPUT

Site Geometry and Soil Parameters

The geometric and soil parameters are listed in the output to provide a check. This output should be checked first when debugging.

Factored Soil Parameters

Factored soil parameters are used to compute the following in each soil layer:

- Depth of soil layer interface (from top of wall)
- Active and passive stress coefficients
- Effective unit weight
- Triangular stress distribution (overburden and horizontal)
- Rectangular stress distribution (overburden and horizontal)
- Resultant force for each stress distribution
- Centroid for each stress distribution
- Moment arm for each stress distribution
- Resultant moment for each stress distribution

Depth of Penetration

The required penetration depth is printed out. If the subgrade cohesion renders an unstable wall, a message reading "THIS WALL CANNOT STAND" will appear and the program will terminate. The stability number of factor of safety against failure in penetration are listed for cohesive subgrades.

Unfactored Soil Parameters

A listing appears of the same parameters output for "Factored Soil Parameters," the difference being that this listing is computed for tie-rods loads and bending moments using unfactored soil parameters.

Tie-Rod Load

The tie-rod load is listed in lb/ft of wall.
Maximum Moment

The maximum bending moment, as computed by the Free Earth Support method is displayed. The location of the maximum moment is also shown (point of zero shear).

Operating and Structural Curves

Ordered pairs of \( \tau \) and \( \log \rho \) are shown for A328 steel sections, A570/A690 steel sections, and wood piles. Ordered pairs are first given for typical sections, then the actual design section. Curve-fitting data is given for clay subgrades where there are only three values of pile flexibility given in the Rowe reduction curves. The value of representing the point of intersection of the operating and structural curves is shown.

Design Section Modulus

The results of the Rowe reduction procedure are listed in \( \text{in}^3/\text{ft} \) of wall for A328 steel, A570/A690 steel and timber.

Design Section

The final USS section is listed for A328 steel, A570/A690 steel, as well as the required actual thickness for a timber pile. The tie-rod load is also output.
### Soil Layers

<table>
<thead>
<tr>
<th>Soil Layer</th>
<th>Depth (ft)</th>
<th>Unit Weight (pcf)</th>
<th>PMI</th>
<th>Cohesion (psf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.000</td>
<td>100.000</td>
<td>30.000</td>
<td>0.000</td>
</tr>
<tr>
<td>2</td>
<td>12.000</td>
<td>122.000</td>
<td>32.000</td>
<td>0.000</td>
</tr>
<tr>
<td>3</td>
<td>180.000</td>
<td>122.000</td>
<td>32.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

- **Wall HT:** 12.00 FT
- **Low MR:** 6.00 FT
- **Top Rod:** 10.50 FT
- **Surcharge:** 0.00 Pounds (point load)
- **Fill Slope:** 45.00 Degrees
- **Dredge Slope:** 0.00 Degrees

### Anchored Bolt Head

<table>
<thead>
<tr>
<th>Layer</th>
<th>KP</th>
<th>RA</th>
<th>Gamma</th>
<th>ZCR</th>
<th>Overburden Stress</th>
<th>Forces</th>
<th>Centroids</th>
<th>Moment Arms</th>
<th>Moments</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4.0</td>
<td>0.60</td>
<td>0.40</td>
<td>100.00</td>
<td>200, 400</td>
<td>-326, -326</td>
<td>2, 3</td>
<td>-4</td>
<td>1, 0</td>
</tr>
<tr>
<td>3</td>
<td>12.0</td>
<td>0.60</td>
<td>0.38</td>
<td>40.00</td>
<td>600, 400</td>
<td>-1034, -1034</td>
<td>4, 5</td>
<td>-6</td>
<td>1, 0</td>
</tr>
<tr>
<td>1</td>
<td>18.0</td>
<td>0.60</td>
<td>0.38</td>
<td>60.00</td>
<td>1049, 366</td>
<td>-1931, -1931</td>
<td>14, 15</td>
<td>-3284, 46150</td>
<td></td>
</tr>
</tbody>
</table>

### Unfactored Soil Parameters

<table>
<thead>
<tr>
<th>Layer</th>
<th>KP</th>
<th>RA</th>
<th>Gamma</th>
<th>ZCR</th>
<th>Overburden Stress</th>
<th>Forces</th>
<th>Centroids</th>
<th>Moment Arms</th>
<th>Moments</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>4.0</td>
<td>0.60</td>
<td>0.28</td>
<td>100.00</td>
<td>200, 400</td>
<td>-224, -224</td>
<td>2, 3</td>
<td>-4</td>
<td>1, 0</td>
</tr>
<tr>
<td>12.0</td>
<td>0.60</td>
<td>0.26</td>
<td>40.00</td>
<td>600, 400</td>
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<tr>
<td>18.0</td>
<td>0.60</td>
<td>0.26</td>
<td>60.00</td>
<td>1049, 366</td>
<td>-1931, -1931</td>
<td>14, 15</td>
<td>-3284, 46150</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Depth of Penetration

- **6.10 FT**

### Tie-Add Pull

- **1199. LBF**

### Zero Skh & Z = 0.0 FT Below Ground Surface...

### Maximum Moment

- **3289.75 FT-LBS**

### A330: Steel Operating and Structural Curves

#### Typical Section

<table>
<thead>
<tr>
<th>LBG RND</th>
<th>LBG RND</th>
<th>LBG RND</th>
<th>LBG RND</th>
<th>LBG RND</th>
<th>LBG RND</th>
</tr>
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<td>LBG RND</td>
<td>LBG RND</td>
<td>LBG RND</td>
<td>LBG RND</td>
<td>LBG RND</td>
</tr>
<tr>
<td>LOG PHI</td>
<td>TQ</td>
<td>TS</td>
<td>TQ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1.720</td>
<td>2.204</td>
<td>2.622</td>
<td></td>
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<td>4.154</td>
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<tr>
<td>-2.100</td>
<td>3.185</td>
<td>4.046</td>
<td></td>
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<tr>
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<td>3.351</td>
<td>5.650</td>
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<td>-2.300</td>
<td>3.571</td>
<td>6.837</td>
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<td>-2.400</td>
<td>3.781</td>
<td>7.660</td>
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<td>4.061</td>
<td>8.354</td>
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<td>4.341</td>
<td>10.812</td>
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**TAU = 2.493**

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**A572/600 STEEL OPERATING AND STRUCTURAL CURVES**

**SPECIFIC SECTION**

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**TAU = 3.165**

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**WOW Operating AND Structural CURVES**

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### Section Material

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<td>1.9</td>
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<td>52/680</td>
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### Cantilevered Bulkhead

#### Factored Soil Parameters

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### Unsaturated Soil Parameters

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<tr>
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<td>1.0</td>
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<tr>
<td>kK</td>
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### Net Heads of Hydrostatic Pressure

- P1 = 15.48 ft

---

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<th>Tie Rod Pull</th>
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<td>1.9</td>
<td>2.5</td>
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<td>P1: 29</td>
<td>52/680</td>
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<td>2.5</td>
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### Wood Operating and Structural Curves

**Typical Section**

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<th>Design</th>
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<td>PHA 22</td>
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**Wood Pile Thickness (in)**

| 4.73 | 4.7 | 9981 |

### Calculated Section Moduli

- 5.938 in·3 (A328)
- 3.981 in·3 (6-572/690)
- 4.016 in·3 (4-WOOD)

**Tau**

- 4.052
APPENDIX D: FLOW TABLES FOR DESIGN

Table D-1. Preliminary actions

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<th>Step</th>
<th>Action</th>
<th>Reference Section</th>
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<tr>
<td>1</td>
<td>Establish soil profile</td>
<td>4.2</td>
</tr>
<tr>
<td>2</td>
<td>Determine bulkhead type (fill or dredge, anchored or cantilevered) and geometry, i.e., wall height, anchor level, dredge level, high and low water levels</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Determine soil parameters for each soil layer ($\phi, c, \gamma$)</td>
<td>4.2</td>
</tr>
<tr>
<td>4</td>
<td>Compute soil stress coefficients using factored soil parameters ($\phi', c'$) for penetration depth and unfactored ($\phi, c$) for tie-rod and moment calculations</td>
<td>2.3.1, Eq. 2-2, 2-3, 4.3</td>
</tr>
<tr>
<td>5</td>
<td>Compute stability number for walls in clay</td>
<td>4.5, Eq. 4-17</td>
</tr>
<tr>
<td>6</td>
<td>Produce a soil stress diagram to aid in calculations</td>
<td>4.3.1, 4.5</td>
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</table>
Table D-2. Free Earth Support calculations

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<th>Reference Section</th>
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<tr>
<td>1</td>
<td>Compute soil stresses, resultant forces, centroids sum moments about</td>
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<tr>
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<td>a. Tie-rod (anchored walls in sand)</td>
<td>4.3.1</td>
</tr>
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<td>b. Tie-rod (anchored walls in clay)</td>
<td>4.5.1</td>
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<td></td>
<td>c. Pile toe (cantilevered walls in sand)</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>d. Pile toe (cantilevered walls in clay)</td>
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<tr>
<td>2</td>
<td>Solve for penetration depth, D, using factored soil parameters for</td>
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<tr>
<td></td>
<td>a. Anchored walls in sand</td>
<td>4.3.1</td>
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<td>b. Anchored walls in clay</td>
<td>4.5.1</td>
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<td></td>
<td>c. Cantilevered walls in sand</td>
<td>4.4</td>
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<tr>
<td></td>
<td>d. Cantilevered walls in clay</td>
<td>4.5.3</td>
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<tr>
<td>3</td>
<td>Compute tie-rod pull, P (force per unit length of wall) by summing</td>
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<td>moments about</td>
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<td>a. 2/3D (anchored walls in sand)</td>
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<td>b. 1/2D (anchored walls in clay)</td>
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<td>Find point of zero shear for:</td>
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<td></td>
<td>a. Anchored walls</td>
<td>4.3.1, 4.5.1</td>
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<td>b. Cantilevered walls</td>
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<td>5</td>
<td>Compute maximum bending moment at point of zero shear</td>
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Table D-3. Rowe reduction calculations

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<td>Compute $M_{\text{max}}$ from FES maximum moment</td>
<td>4.3.1, 4.4, 4.5.1</td>
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<td>2</td>
<td>Develop an operating curve based upon $M_{\text{max}}$ and moment reduction factors for</td>
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<tr>
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<td>a. Anchored walls in sand</td>
<td>4.3.1</td>
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<td>b. Anchored walls in clay</td>
<td>4.5.1</td>
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<td>c. Cantilevered walls in sand</td>
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</tr>
<tr>
<td>3</td>
<td>Develop structural curves based upon the average properties of the sheet pile material under consideration</td>
<td>4.3.1, 4.4, 4.5.1, 2.7.1.3, Fig. 2-17a, 2.7.4, Fig. 2-19a, 2.7.6, Fig. 2-20</td>
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<tr>
<td>4</td>
<td>Find $T$ from the intersection of the operating and structural curves</td>
<td>4.3.1, 4.4, 4.5.1, 2.7.1.3, Fig. 2-18</td>
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<td>Determine the member size from $T$</td>
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<td>Recompute the structural curve based upon the properties of the selected section</td>
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<td>Repeat steps 4 and 5 to insure that the selected section is adequate</td>
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<td>Apply tie-rod factors</td>
<td>4.3.1, 2.3.7.1, Fig. 2-17b</td>
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<td>a. Walls in sand</td>
<td>4.5.1, 2.7.4, Fig. 2-19b</td>
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<td>b. Walls in clay</td>
<td>2.7.1.3, Fig. 2-17c</td>
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<td>c. Non-yielding anchorages</td>
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<td>Compute loading ratio, R</td>
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<td>2</td>
<td>Compute modifying coefficient for depth, $C_D$</td>
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<td>Compute $R_D = R \times C_D$, find dimensionless depth, $D'$ from design charts or equations</td>
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<td>Compute $D = D' \times H$</td>
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<tr>
<td>5</td>
<td>Compute modifying coefficient for moment and tie-rod pull, $C_M = C_P$</td>
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<td>Compute $R_M = R \times C_M$, find dimensionless bending moment, $M'$, from charts or equation</td>
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<td>Compute moment $M = M' \gamma_3 L^3$</td>
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<td>Compute $R_P = R \times C_P$, find dimensionless tie-rod pull, $P'$</td>
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<td>Compute pull, $P = P' \gamma L^2$</td>
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<td>b. Apply load factors</td>
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<td>c. Compute required diameter</td>
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<td>d. Determine length based on anchorage location</td>
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<td>Wale design</td>
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<td>b. Dimension the wale</td>
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<td>Fastening wales to sheet piles</td>
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<td>a. Inside wales, wood: select a nail size and determine the number of nails required per section to resist the prying force, P (tie-rod pull/unit length of wall)</td>
<td>5.4.3.1</td>
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<td>b. Outside wales, wood: use 2 nails/pile. Select nail size with adequate length to transmit shear</td>
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<tr>
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<td>c. Inside wales, steel</td>
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<td>1) Select a bolt size and determine the number of bolts required to resist the prying force, P (tie-rod pull/unit length of wall)</td>
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<td>2) Compute tensile force in each bolt</td>
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<td>3) Compute bending moment in fixing plate</td>
<td>5.4.3.3</td>
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<td>4) Dimension the fixing plate</td>
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<td>d. Outside wale, steel: use number of bolts required to facilitate construction</td>
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</table>
Table D-5. Continued

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Reference Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Splices for wales</td>
<td>5.4.3.2</td>
</tr>
<tr>
<td></td>
<td>a. Outside wales, wood: locate splices at the tie-rod. Design a bearing plate for the tie-rod nut</td>
<td>5.4.3.2</td>
</tr>
<tr>
<td></td>
<td>b. Inside wales, wood:</td>
<td>5.4.3.2</td>
</tr>
<tr>
<td></td>
<td>1) Select splice plate dimensions (2- or 3-member splice) to resist maximum moment in wale</td>
<td>5.4.3.2</td>
</tr>
<tr>
<td></td>
<td>2) Select bolt size and number to resist shear</td>
<td>5.4.3.2</td>
</tr>
<tr>
<td></td>
<td>3) Determine edge distance, end distance, spacing between bolts, and spacing between rows</td>
<td>5.4.3.2</td>
</tr>
<tr>
<td></td>
<td>4) Select final length of splice plate</td>
<td>5.4.3.2</td>
</tr>
<tr>
<td></td>
<td>c. Splices for channels</td>
<td>5.4.3.2</td>
</tr>
<tr>
<td></td>
<td>1) Select splice plate width and thickness to fit between the channel flanges and to resist maximum moment in the wale</td>
<td>5.4.3.2</td>
</tr>
<tr>
<td></td>
<td>2) Select bolts to resist shear (double shear as bolts will attach 2 plates, one on each channel)</td>
<td>5.4.3.2</td>
</tr>
<tr>
<td></td>
<td>3) Allow for edge distance and spacing</td>
<td>5.4.3.2</td>
</tr>
<tr>
<td></td>
<td>4) Select a convenient length</td>
<td>5.4.3.2</td>
</tr>
<tr>
<td>5</td>
<td>Anchorage design</td>
<td>5.4.4</td>
</tr>
<tr>
<td></td>
<td>a. Determine loads on:</td>
<td>5.4.4.1</td>
</tr>
<tr>
<td></td>
<td>1) Continuous anchorage</td>
<td>5.4.4.2</td>
</tr>
<tr>
<td></td>
<td>2) Short deadman</td>
<td>5.4.3.2</td>
</tr>
<tr>
<td></td>
<td>b. Check bearing stress of tie-rod nut and design a bearing plate, if required</td>
<td>5.4.3.2</td>
</tr>
</tbody>
</table>
APPENDIX E

DESIGN EXAMPLES

EXAMPLE #1: GIVEN THE FOLLOWING SITE GEOMETRY AND SOIL CONDITIONS, FIND THE PENETRATION DEPTH, BENDING MOMENT AND TIE-ROD PULL USING THE FREE EARTH SUPPORT METHOD WITH ROWE REDUCTION:

\[ H = 12' \quad t_1 = 4' \quad \gamma_1 = 100 \text{ psf} \quad \theta_1 = 30^\circ \] (FIG. 4-1)
\[ H_w = 8' \quad t_2 = 6' \quad \gamma_2 = 122.4 \text{ psf} \quad \theta_2 = 32^\circ \]
\[ H_a = 2' \quad \gamma_3 = 122.4 \text{ psf} \quad \theta_3 = 32^\circ \]

1. FIND FACTORED AND UNFACTORED SOIL PARAMETERS

\[ \theta_1 = 30^\circ \quad \gamma_1 f = \gamma_1 / (1.5 \gamma_1 \sin 30^\circ) = 2^\circ \] (EQ 2-1)
\[ \theta_2 = 32^\circ \quad \gamma_2 f = 22.4^\circ \times 93.6^\circ \]
\[ \theta_3 = 20^\circ \quad \gamma_3 f = 14^\circ \]
\[ \theta_2 = 21.3^\circ \quad \gamma_2 f = 15^\circ \times 59.6^\circ \]

\[ K_a = \frac{\cos^2 \theta}{\sqrt{1 + \sin (2 - \theta) \sin \theta}} \] (EQ 2-2)
\[ K_p = \frac{\cos^2 \theta}{\sqrt{1 + \sin (3 - \theta) \sin \theta}} \] (EQ 2-3)

FACTORED:
\[ K_{a1} = 0.403 \quad K_{a2} = 2.182 \times K_{a3} \quad K_{p1} = 3.62 \times K_{p3} \]

UNFACTORED:
\[ K_{a1} = 0.279 \quad K_{a2} = 2.356 \times K_{a3} \quad K_{p1} = 5.33 \times K_{p3} \]

\[ \gamma_2 = 22.4 - 22.4 \times 60 \text{ psf} = \gamma_3 \]

\[ \text{(SOIL UNIT WEIGHT)} \]
2) Compute resultant forces and sum moments about tie rod (Fig. 4-2, Eq. 4-3)

\[
\begin{align*}
\frac{1}{2} k_a \gamma_1 \gamma_1 \left( \frac{1}{3} a + \frac{2}{3} D \right) + \frac{1}{2} k_a \gamma_2 \gamma_2 \left( \frac{1}{3} \epsilon_0 + \frac{2}{3} D \right) + k_a \gamma_3 \gamma_3 (H - c - HA) &= 0 \\
\left( \frac{1}{2} \epsilon_1 + \frac{2}{3} a - HA \right) + k_a (\gamma_1 \gamma_1 + \gamma_2 \gamma_2) \gamma_3 (H - c - HA) &= \frac{1}{2} (k_p^2 + k_p) \\
y_3 D^2 \left( \frac{1}{3} D + H - HA \right) &= 0
\end{align*}
\]

\[
28 - 9330 - 7330 + 33600 - (148 - 881) D^2 - 58.8 D^3 = 0 \\
12,930 + 33600 - 713 D^2 - 58.8 D^3 = 0 \\
D = 5.3' 
\]

3) Compute toe shear based upon \( k_o + H = 0 = 17.4 \)

\[
\begin{align*}
(F_T) &= (F_T) + (F_T) + (F_T) + (F_T) \tan S = \\
\left[ \frac{1}{2} k_a \gamma_1 \gamma_1 + \frac{1}{2} k_a \gamma_2 \gamma_2 + k_a \gamma_3 \gamma_3 (H - c - HA) \right] \tan S + \\
- \frac{1}{2} (k_p^2 - k_p) \gamma_3 D^2 \tan S \\
(320 + 753 + 1,220 + 1,880 - 2760) \tan 14^\circ &= 349 \#
\end{align*}
\]

For weight of pile per foot of height use \( W = 22' \) ft

\[
T_S = \left[ (F_T) \tan 14^\circ + (349) \right] \tan 14^\circ = 184 '\
\]

4) Apply force at \( \frac{2}{3} D \) and sum moments about tie rod:

\[
T_S (H - \frac{2}{3} D - HA) = (184)(13.7) = 2530 \\
(1,2930 - 2,530) + 33600 - 713 D^2 - 58.8 D^3 = 0 \\
10,400 + 33600 - 713 D^2 - 58.8 D^3 = 0 \\
D = 8.3', \text{ use } D = 5.5'
\]

5) Find tie rod using unfactored soil parameter by summing moments of resultant forces about \( \frac{2}{3} D \) (Eq. 4-3)

\[
\begin{align*}
\frac{1}{2} k_a \gamma_1 \gamma_1 \left( \frac{1}{3} a - \frac{2}{3} a + \frac{2}{3} D \right) + \frac{1}{2} k_a \gamma_2 \gamma_2 \left( \frac{1}{3} \epsilon_0 - \frac{2}{3} D \right) + k_a \gamma_3 \gamma_3 (H - c - HA) &= 0 \\
k_a \left( \gamma_1 \gamma_1 + \gamma_2 \gamma_2 \right) (\frac{2}{3} D) - P (H - \frac{2}{3} D - HA) &= 0 \\
(2900 + 3110 + 6280 - 1140) &= 13.7 P \\
P_{285} &= 983 ' / ft
\end{align*}
\]
4) FIND POINT OF ZERO SHEAR

\[ P = F_t - 2.020 Y^2 x^2 - K_0 Y_0 x = 0 \]

\[ x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \]

WHERE
\[ a = 2K_0 Y_0 = 7.48 \]
\[ b = K_0 Y_0 Y_2 + 4Y_0 \text{ ING} \]
\[ c = F_t + 2.52K_0 Y_0 x^2 - 740 \]

\[ x = 0.72 \text{" below the water line (z,)} \]

7) FIND MAXIMUM MOMENT

\[ M_{\text{max}} = \beta (9.5 - x - 0.4) = F_t (\frac{4}{3} + x) \frac{1}{2} K_0 Y_0 x^2 + \frac{1}{2} K_0 Y_0 x \frac{1}{2} \]

\[ = 560(5.72) - (223)(8.05) - (7.7) - (7310) \]

\[ = 3690 \text{ ft} \cdot \text{lb} \]

8) COMPUTE TIE-ROD LOAD BASED UPON ROWE METHOD:

\[ \alpha = \frac{0.2}{4} = 0.05 \]
\[ \beta = \frac{0.2}{4} = 0.11 \]

\[ \gamma_c = 1.02 \] (Fig. 2.176)

\[ P = \frac{F_c \cdot P_{\text{req}}}{1.02} \]
\[ P = 1.02(983) = 1000 \text{ lb.} \]

For spacing of ties at 7" centers
\[ T = P \cdot 7.5 = 7500 \text{ lb.} \]

9) COMPUTE BENDING MOMENT

\[ M_{\text{max}} = (9.5) M_{\text{max}} / 100 = (9.5)(3690) \text{ ft} \cdot \text{lb} \]

\[ = 826 \text{ (Eq. 4.4-8)} \]

Using Fig. 2.176 for values of \( h_4 \): Interpolate 0.20 \( h_4 \) distance between loose sand and dense sand \( h_4 \approx 0.7 \). Use of

\[ 20\% \text{ for interpolation stems from choosing } \theta = 30^\circ \]

For loose sand, \( \theta = 40^\circ \) for dense sand, and \( \theta = 32^\circ \)

For the subgrade so that:

\[ 32 - 30 \]

\[ 40 - 30 = 20\% \]
\[ T_{op} = T_{max} \times n \delta \]  
\[ T_{str} = \frac{u}{(h_0p)^n} \]  
\[ \psi = 2 \frac{\delta}{L} \bigg( \frac{12(2000)}{(1.5 \times 10^6)^n} \bigg)^{0.309} \]  
\[ = 0.240 \text{ (APPROX. FOR A328 STEEL)} \]  
\[ = 0.400 \text{ (APPROX. FOR A690 STEEL)} \]  

<table>
<thead>
<tr>
<th>( \delta )</th>
<th>(-3.00)</th>
<th>(-2.75)</th>
<th>(-2.50)</th>
<th>(-2.25)</th>
<th>(-2.00)</th>
<th>(-1.75)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rd</td>
<td>0.97</td>
<td>0.48</td>
<td>0.39</td>
<td>0.29</td>
<td>0.27</td>
<td>0.27</td>
</tr>
<tr>
<td>Top</td>
<td>4.94</td>
<td>3.97</td>
<td>3.22</td>
<td>2.61</td>
<td>2.40</td>
<td>2.23</td>
</tr>
<tr>
<td>((H_0p^2))^{\frac{1}{2}}</td>
<td>30.5</td>
<td>24.2</td>
<td>17.9</td>
<td>12.2</td>
<td>8.30</td>
<td>3.85</td>
</tr>
<tr>
<td>Tstr (wood)</td>
<td>11.6</td>
<td>8.0</td>
<td>5.45</td>
<td>3.71</td>
<td>2.53</td>
<td>1.17</td>
</tr>
<tr>
<td>(A328)</td>
<td>10.0</td>
<td>4.81</td>
<td>4.69</td>
<td>3.17</td>
<td>2.16</td>
<td>1.60</td>
</tr>
<tr>
<td>(A690)</td>
<td>12.4</td>
<td>7.16</td>
<td>4.86</td>
<td>3.32</td>
<td>2.26</td>
<td>1.54</td>
</tr>
</tbody>
</table>

(SEE PLOT NEXT PAGE)

b) DESIGN SECTION

\[ M = T \cdot \delta \]  
\[ \delta = \frac{M}{T} \]  

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>( T ) (ft-lb)</th>
<th>( M ) (in-lb)</th>
<th>( T ) (psi)</th>
<th>( S ) (in^3/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WOOD</td>
<td>2.37</td>
<td>12,700</td>
<td>2,000</td>
<td>4.39</td>
</tr>
<tr>
<td>A328</td>
<td>2.48</td>
<td>13,300</td>
<td>25,000</td>
<td>0.922</td>
</tr>
<tr>
<td>A690</td>
<td>2.22</td>
<td>11,900</td>
<td>32,000</td>
<td>0.372</td>
</tr>
</tbody>
</table>

FOR WOOD SECTION:

\[ S = \frac{h}{2} \sqrt{\frac{b}{2}} \]  
\[ a = 1.78, \text{ USE } 3 \times 12 \text{ (NOMINAL SIZE)} \]

FOR A328 & A690 STEEL, THE SMALLEST SECTION, AS28 HAS

\[ S = 1.9 \text{ in}^3/\text{ft} > S_{req.} \]  

(TABLE 5.2)
c) RECOMPUTE FLEXIBILITY CHARACTERISTICS:

\[ \psi = \frac{f}{E} \cdot \frac{S}{S} \quad \text{(Eq. 4.13)} \]

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>f (psi)</th>
<th>E (psi)</th>
<th>S (in^3/ft^2)</th>
<th>I (in^4/ft)</th>
<th>\psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>A328</td>
<td>25,000</td>
<td>30 x 10^6</td>
<td>1.9</td>
<td>2.6</td>
<td>0.248</td>
</tr>
<tr>
<td>A690</td>
<td>32,000</td>
<td>30 x 10^6</td>
<td>1.9</td>
<td>2.6</td>
<td>0.317</td>
</tr>
</tbody>
</table>

d) RECOMPUTE \( T_{str} \) AND FIND INTERSECTION OF THE OPERATING AND NEW STRUCTURAL CURVES FOR A328 AND A690 STEEL:

<table>
<thead>
<tr>
<th>log ( \psi )</th>
<th>-2.25</th>
<th>-1.50</th>
<th>-1.00</th>
<th>-0.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>( (H_o g^3)^{0.5} )</td>
<td>12.2</td>
<td>9.33</td>
<td>6.66</td>
<td>3.89</td>
</tr>
<tr>
<td>( T_{str} ) (A328)</td>
<td>3.03</td>
<td>2.36</td>
<td>1.40</td>
<td>0.95</td>
</tr>
<tr>
<td>( T_{str} ) (A690)</td>
<td>4.65</td>
<td>3.89</td>
<td>3.12</td>
<td>2.17</td>
</tr>
<tr>
<td>T_{opt}</td>
<td>2.81</td>
<td>2.40</td>
<td>2.23</td>
<td>2.23</td>
</tr>
</tbody>
</table>

e) RECOMPUTED VALUES:

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>T</th>
<th>Min.</th>
<th>Spec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A328</td>
<td>2.66</td>
<td>2,300</td>
<td>0.572</td>
</tr>
<tr>
<td>A690</td>
<td>2.21</td>
<td>1,800</td>
<td>0.307</td>
</tr>
</tbody>
</table>

The sections selected are satisfactory. A cost analysis will determine which material is best: wood, A328 or A690.
EXAMPLE 2: USING THE CONDITIONS OF EXAMPLE #1, ASCERTAIN THE DESIRABILITY OF A CANTILEVERED WALL.

1) COMPUTE DEPTH OF PENETRATION: SUM MOMENTS ABOUT TOE

\[ \frac{1}{2} k_0 x_1 x_2^2 \left( \frac{1}{3} t_e \cdot x_e \cdot 0 \right) + \frac{1}{2} k_0 y_2 x_2^2 \left( \frac{1}{3} t_2 \cdot x_2 \cdot 0 \right) + k_0 x_1 x_2 \left( \frac{1}{5} t_e \cdot x_e \cdot 0 \right) + k_0 y_2 \left( y_2 \cdot x_1 - y_2 \cdot x_2 \right) \cdot D^2 \]

\[ + \frac{1}{2} \left( k_0 y_2 - k_e \right) y_2 D^3 = 0 \]

\[ 321 (9.33 \cdot 0) + 738 (2.67 \cdot 0) + 1220 (4 - 0) + 168 D^2 - 29.40 D^3 = 0 \]

\[ D = 13.4 \]

2) NEGLECT TOE SHEAR: MOMENT ARM IS \( \frac{1}{2} D \) AND THE RESULTING MOMENT COMPUTED FROM TOE SHEAR IS VERY SMALL.

3) FIND MAXIMUM MOMENT:

a) POINT OF ZERO SHEAR IS SOME DISTANCE \( X \) BELOW CRACK LEVEL (USE UNFACTORED SOIL PARAMETERS)

\[ F_1 - F_2 - F_{R_2} = k_{o_3} (x_1 \cdot x_2 + y_2 \cdot x_2) \cdot x - \frac{1}{2} (k_o - k_{o_3}) y_3 \cdot x^2 = 0 \]

\[ (224 + 492 + 819) - 225 x - 197 x^2 \]

\[ x = \frac{-b - \sqrt{b^2 - 4ac}}{2a} \]

where \( a = 197 \), \( b = -225 \), \( c = -1335 \)

\[ x = 3.42 \]

b) \( M_{\text{MAX}} = F_1 \left( \frac{1}{3} t_e \cdot x_e + x \right) - F_{R_2} \left( \frac{1}{3} t_2 \cdot x_2 + x \right) + k_{o_3} \left( \frac{1}{5} t_e \cdot x_e \cdot x^2 \right) - \frac{1}{2} (k_o - k_{o_3}) y_3 x^3 \]

\[ = (224) (12.9) + (492) (4.28) + (819) (7.61) \]

\[ + \frac{1}{2} (225) (3.41)^2 - \frac{1}{2} (396) (3.41)^3 \]

\[ = 1091.6 ft \cdot \# \]

4) COMPUTE BENDING MOMENT (WOOD ONLY)

a) \( T_{\text{MAX}} = M_{\text{MAX}} \cdot 12 \cdot \frac{wD}{3} \)

\[ = (1091.6) (12) / ((13.4 + 12)^3) \]

\[ = 3.00 \]
b) \( \alpha = \frac{H}{H_0} = \frac{(12)}{(15.4-12)} = \frac{(12)}{(23.4)} = 0.472 \)

c) Generate operating and structural curves. From Fig. 3.4, select values of \( H \) for the corresponding values of \( \log \rho \):

\[
\begin{align*}
\psi_{op} &= \phi_{max} \times \rho_{d} \\
\psi_{st} &= \frac{20}{\psi_{V2}} \cdot \frac{(2)(1000)}{(1.3)(100)} = 0.305
\end{align*}
\]

For wood, \( \psi = \frac{20}{\psi_{V2}} \cdot \frac{(2)(1000)}{(1.3)(100)} = 0.305 \)

<table>
<thead>
<tr>
<th>( \log \rho )</th>
<th>-3.0</th>
<th>-2.75</th>
<th>-2.50</th>
<th>-2.25</th>
<th>-2.00</th>
<th>-1.75</th>
<th>-1.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho_d )</td>
<td>0.40</td>
<td>0.53</td>
<td>0.49</td>
<td>0.48</td>
<td>0.45</td>
<td>0.44</td>
<td>0.44</td>
</tr>
<tr>
<td>( \psi_{op} )</td>
<td>4.60</td>
<td>4.74</td>
<td>4.92</td>
<td>5.12</td>
<td>5.40</td>
<td>5.72</td>
<td>6.02</td>
</tr>
<tr>
<td>( \psi_{st} )</td>
<td>34.0</td>
<td>23.2</td>
<td>15.8</td>
<td>10.5</td>
<td>7.33</td>
<td>4.99</td>
<td>3.40</td>
</tr>
<tr>
<td>( H_0^{1/3} )</td>
<td>10.4</td>
<td>7.07</td>
<td>4.82</td>
<td>3.28</td>
<td>2.22</td>
<td>1.52</td>
<td>1.04</td>
</tr>
</tbody>
</table>

It can be seen from inspection, that the intersection of the graphs falls between \( \log \rho = -2.50 \) and \( \log \rho = -2.25 \). Approximating the structural and operating curve segments as straight and employing simple coordinate geometry yields:

\[
T = 3.37 \times 10^4 \quad \log \rho = -2.35
\]

\[
M = T \times H_0 = (3.37)(10^4) = 3.342 \times 10^4 \text{ in-lb}
\]

\[
S = \frac{M}{P} = \frac{3.342 \times 10^4}{2000} = 1.67 \text{ in}^3
\]

\[
S = \frac{1}{6} \pi b^2, \text{ for } b = 12\text{ in, } \frac{1}{6} \pi \frac{12^2}{6} = \sqrt{3} \text{ in}
\]

\[
e = 3.98 \text{ in}
\]
9 x 12 (Nominal) sheet-piles are required. This size section is probably not available. A steel section or navy wall would be appropriate.

For A328 steel:

\[ \psi = 0.260 \]

For wood:

\[ \psi = 0.365 \]

Forming a ratio of A328/wood and applying it against the existing values of \( T \) precludes generating another structural curve.

For \( \log \rho = -2.25 \), \( T_{st} = \frac{(0.260)}{0.365} (3.28) = 2.79 \)

For \( \log \rho = -2.50 \), \( T_{st} = \frac{(0.260)}{0.365} (4.32) = 4.10 \)

This segment of the curves is identified by:

\[
\begin{align*}
\log \rho & \quad -2.50 & -2.25 \\
T & \quad 3.92 & 3.34 \\
T_{st} & \quad 4.10 & 2.79
\end{align*}
\]

\[
T = 3.91
\]

\[
M = (3.91)(23.4)^3 = 64,100 \text{ in} \cdot \text{lb}
\]

\[
S = \frac{M}{T} = \frac{(64,100)}{23,000} = 2.76 \text{ in}^3
\]
Use PMAZ, where $S = 5.4 \text{ m}^3$ no recomputation is needed as the section modulus is substantially greater than the minimum required.

3) The cantilevered wall is much less economical owing to the great increases in the required section and overall pile length.

Example 3: Using conditions given in Example 1, find the penetration depth, tie-rod load and bending moment, using the design charts:

1) Compute $R_0$:

$$R = \frac{y_1^2 + y_2^2}{y_1^2 + y_2^2} = \frac{(60)(4)^3 - (60)(6)^3}{(60)(12)^3}$$

$$= 0.358$$

$$c_0 = \left(\frac{12}{24}\right)^2 \left(\frac{24 - 12}{12}\right) = \left(\frac{6}{12}\right)^2 \left(\frac{12}{12}\right)$$

$$= 0.0689$$

$$R_0 = p \cdot c_0 = (0.358)(0.0689) = 0.0318$$

2) Find $D'$, since the subgrade is somewhere between the "loose" and "medium" conditions, interpolation will give the desired values.

Enter Fig. 4.4 and read off $D'$ for "L/L" and "L/M." Interpolation by considering the desired value to be 0.40 times the distance from "L/L" to "L/M" gives the proper value.

<table>
<thead>
<tr>
<th>Condition</th>
<th>$c_0$</th>
<th>$c'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>L/L</td>
<td>0.503</td>
<td>0.503</td>
</tr>
<tr>
<td>Desired</td>
<td>$0.503 - x$</td>
<td>$0.503 - x$</td>
</tr>
<tr>
<td>L/M</td>
<td>0.336</td>
<td>0.336</td>
</tr>
</tbody>
</table>

$$x = 0.167$$

$$D' = 0.434 = D = D' \cdot h = (0.436)(12) = 5.23$$
3) \textbf{Compute } RM/LP_a; \\
RM = R_p = R_s + CH + C_d \\
C_d = CM = (\frac{D}{H}) (\frac{H_A}{M_H}) = (\frac{5.23}{12}) (\frac{2}{8}) = 0.109 \\
RM = R_s + CM = (0.358) (0.109) = 0.039 = R_p \\

4) \textbf{Find } M' \textbf{; Interpolate by entering } "L/L\text{" and } "L/M\text{" at } RM = 0.039 \\

\begin{array}{ccc}
\text{condition} & \text{L/L} & \text{L/M} \\
\text{Desired} & 32 & 39 \\
\text{Desired} & 20 & 39 \\
\end{array}

\begin{align*}
L &= \frac{2}{3} D - H - H_A = (\frac{2}{3})(5.23) + 12 - 2 \\
&= 13.5 \\
M' &= M_s L^3 = (0.103)(60)(13.5)^3 \\
&= 15,200 \text{ in-lb} \text{ (A328 steel)}
\end{align*}

5) \textbf{Find } \rho' \textbf{; Enter } "L/L\text{" and } "L/M\text{" for } R_p = 0.041 \\

\begin{array}{ccc}
\text{condition} & \text{L/L} & \text{L/M} \\
\text{Desired} & 30 & 39 \\
\text{Desired} & 20 & 39 \\
\end{array}

\begin{align*}
\frac{X}{0.035} &= \frac{2}{3} \\
X &= 0.0231 \\
\rho &= 0.0422 \\
\rho &= \rho' \sqrt{L^2} = (0.0422)(100)(13.5)^{\frac{1}{2}} = 1130 \text{ lb/ft}^2
\end{align*}
4) The percent difference between the results using the design charts with the results of the hand calculations are:

Penetration depth : -1.3%
Bending moment : 4.3%
Tie-rod pull : 18.0%

Example 4: Consider the site geometry of Example 1 and the following soil conditions and compute the penetration depth, bending moment and tie-rod pull:

\[ \alpha_1 = 30^\circ \quad y_1 = 100 \text{ pcf} \]
\[ \alpha_2 = 30^\circ \quad y_2 = (120 - 62.4) = 57.6 \text{ pcf} \]
\[ \alpha_3 = 0 \quad y_3 = (110 - 62.4) = 47.6 \text{ pcf} \]
\[ y_4 = 300 \text{ pcf} \]

1) Determine stability number and soil parameters:

\[ \sigma_c^* = \frac{C_r}{(300)(1.25)} \frac{(y_2 - y_1)}{(y_3 - y_1)} \frac{\text{cu}}{47.2(2)} = 0.435 > 0.25, \text{ ok} \]

\[ \alpha_1 = 30^\circ, \quad \mu_0 = 0.479 \quad \text{(unfactored)} \]

\[ C^* = \frac{1}{1.5} \frac{300}{100} = 200 \text{ psi} \]

2) Compute resultant forces and sum moments about tie rod:

\[ \frac{1}{2} k_a x_2 \left( \frac{2}{3} x_1 - h_a \right) = \frac{1}{2} k_a y_2 x_2 \left( \frac{2}{3} x_2 - x_1 - h_a \right) = k_a y_2 x_1 x_2 \]

\[ \frac{1}{2} k_o x_2 \left( \frac{2}{3} x_1 + h_a \right) = \left( 4 C_r^* - y_2 \frac{x_1}{x_2} - y_1 x_1 \right) \theta \left( \frac{1}{2} D + h - h_a \right) = 0 \]

\[ 199 + 1770 + 3260 = (39.2) \theta (1/2) (3/8) = 0 \]

\[ 69.6 D^2 + 1114D - 9250 = 0 \]

\[ D = -131 \pm \frac{\sqrt{1824}}{29} \quad \text{where} \quad D = 69.6 \]

\[ C = 9250 \quad \text{if} \quad \theta = 114 \]

\[ C = 9250 \]
3) **Find the rod load by summing moments about $\frac{1}{2}D$:**

\[
\frac{1}{2} k \alpha \tau_1 \tau_2 \left( \frac{1}{3} t_1 + t_2 - \frac{1}{2} D \right) - \frac{1}{2} k \alpha \tau_2 \tau_3 \left( \frac{1}{3} t_2 + \frac{1}{2} D \right) + \\
k \alpha \tau_1 \tau_2 \left( \frac{1}{2} r_2 + \frac{1}{2} D \right) - P \left( \frac{1}{2} D + H - H_0 \right) = 0
\]

\[
2750 + 2910 - 6250 - P(13) = 0
\]

\[P = 916 \text{ ft/lb}\]

4) **Find the point of zero shear**

\[
P = F_{F1} - \frac{1}{2} k \alpha \tau_2 x^2 - k \alpha \tau_1 \tau_x, x = 0
\]

\[
916 - 223 - 2.04 x^2 - 112 x = 0
\]

\[
x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}
\]

**where** \(a = 112\), \(b = 8.04\), \(c = -(916 - 223) = -693\)

\[x = 4.69\]

5) **Compute \(M_{\text{max}}:\)**

\[
M_{\text{max}} = P \left( t_1 + t_2 - H \right) - F_{F1} \left( \frac{1}{3} t_1 + t_2 - \frac{1}{2} D \right) - \frac{1}{2} k \alpha x^3 - \frac{1}{2} k \alpha x^2
\]

\[
= \left( \frac{916}{(4.69)} \right) - \left( 223 \right) \left( 3.98 \right) - \left( 1.34 \right) \left( 4.69 \right)^3 - \left( 56 \right) \left( 4.69 \right)^2
\]

\[= 3412 \text{ ft-lb} = M_{\text{max}}\]

6) **Compute bending moment**

a) \(T_{\text{max}} = (12) M_{\text{max}} / H_0^3 = (12) (3412) / (18)^3\)

\[= \frac{12}{18} = 0.67\]

\[\theta = \frac{12}{18} = 0.67\]
b.) GENERATE OPERATING AND STRUCTURAL CURVES:
\[
T_{op} = T_{max} + T_d \quad (VALUES \ OF \ T_d \ ARE \ FROM \ FIG. \ 3.3a)
\]
\[
T_{op} = \frac{\psi}{(h_0 a^2)^{1/4}} \quad \text{USE } \psi = 0.305 \quad (\text{wood})
\]
\[
\psi = 0.260 \quad (A328)
\]
\[
\psi = 0.400 \quad (A990)
\]

<table>
<thead>
<tr>
<th>( \log \phi )</th>
<th>-3.1</th>
<th>-2.6</th>
<th>-2.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_d )</td>
<td>0.79</td>
<td>0.76</td>
<td>0.71</td>
</tr>
<tr>
<td>( T_{max} )</td>
<td>3.95</td>
<td>3.33</td>
<td>4.98</td>
</tr>
<tr>
<td>( (h_0 a^2)^{1/4} )</td>
<td>44.9</td>
<td>20.6</td>
<td>9.56</td>
</tr>
<tr>
<td>( T_{op} )</td>
<td>13.6</td>
<td>6.23</td>
<td>2.92</td>
</tr>
<tr>
<td>( (A328) )</td>
<td>11.6</td>
<td>5.34</td>
<td>2.49</td>
</tr>
<tr>
<td>( (A990) )</td>
<td>17.8</td>
<td>8.24</td>
<td>3.28</td>
</tr>
</tbody>
</table>

c.) RECOMPUTATION OF \( T_{op} \) IS NOT NECESSARY. INSPECTION OF
THE GRAPH SUGGESTS THAT LITTLE CHANGE IN \( \psi \) WILL RESULT.

d.) \( M = T \cdot \psi \cdot a^3 \)

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>( T )</th>
<th>( M / (\text{in}^5/\text{ft}) )</th>
<th>( f_{ps} / (\text{psi}) )</th>
<th>( b / (\text{in}^2/\text{ft}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>WOOD</td>
<td>5.12</td>
<td>22,400</td>
<td>2,000</td>
<td>15.0</td>
</tr>
<tr>
<td>A328</td>
<td>5.15</td>
<td>30,000</td>
<td>25,000</td>
<td>11.9</td>
</tr>
<tr>
<td>A990</td>
<td>5.07</td>
<td>29,500</td>
<td>37,000</td>
<td>0.92</td>
</tr>
</tbody>
</table>

7.) SELECT MEMBER SIZE:
   a.) WOOD: \( t = \frac{\sqrt{E}}{2} = \frac{\sqrt{15}}{2} = 2.73 \text{ in} \); USE \( 4 \times 12 \) (NOMINAL)
   b.) A328; USE PS 28; \( S = 1.9 > 1.19 \)
   c.) A990; USE PS 28; \( S = 1.9 > 1.19 \)
8) **TIE-ROD LOAD**

a) **From Fig. 3.30, values of \( R_c \) for \( St = 0.435 \) are:**

<table>
<thead>
<tr>
<th>( \log \alpha )</th>
<th>2.1</th>
<th>2.4</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_c )</td>
<td>1.40</td>
<td>1.25</td>
<td>1.05</td>
</tr>
</tbody>
</table>

b) **Values of \( \log \alpha \) can be established from**

\[
\alpha = 10^{R_c / 2.32}
\]

And \( R_c \) can then be interpolated. **The tie-rod load for spacing of 7.46 in then computed by**

\[
T = (7.5) R_c P \text{ for}
\]

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>( E (\text{psi}) )</th>
<th>( I (\text{in}^4/\text{ft}) )</th>
<th>( \alpha )</th>
<th>( R_c )</th>
<th>( P \text{ in} )</th>
<th>( T (\text{ft}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>1.5 x 10^6</td>
<td>38.4</td>
<td>2.74</td>
<td>1.29</td>
<td>916</td>
<td>8350</td>
</tr>
<tr>
<td>A-328</td>
<td>30 x 10^6</td>
<td>2.0</td>
<td>2.30</td>
<td>1.34</td>
<td>916</td>
<td>9230</td>
</tr>
<tr>
<td>A-90</td>
<td>30 x 10^6</td>
<td>2.8</td>
<td>2.90</td>
<td>1.34</td>
<td>916</td>
<td>9230</td>
</tr>
</tbody>
</table>
Example 5: Using the conditions given in Example 3, find the penetration depth, bending moment and tie rod pull, using the design charts.

1. Compute \( R_D \)

\[ R = \frac{\alpha_1^3 + \alpha_2^2}{(4C - \alpha_1 - \alpha_2^2)} \]

\[ = \frac{(100)(4)^3 + (57.6)(8)^3}{[(4)(300) - (150)(2) - (57.6)(8)](12)^2} \]

\[ = 0.390 \]

\[ c = \frac{H_u}{(H - H_u)} \]

\[ = \frac{8}{(12 - 2)(0.433)} = 1.84 \]

\[ R_D = R \cdot c = (0.390)(1.84) = 0.717 \]

2. Compute \( B \): Enter Figure 4-7 \( R_D = 0.717 \) and read off \( D' \) for \( \theta_H = 0.25 \):

\[ D' = 0.488 \]

\[ D = D'H = (0.488)(12) = 5.86' \]

3. Compute \( M \) and \( M' \)

\[ G_m = 1 \]

\[ R_u = R \cdot G_m = 0.390 \]

Enter Figure 4-9 \( R_u = 0.390 \) and read off \( M' \) for \( \theta_H = 0.25 \):

\[ M' = 2.99 = \frac{G_c}{c} \cdot (\alpha + 0.350(\alpha) \cdot (1) \cdot (1)) \]

\[ M = M' \cdot 10^2 \]

\[ M = (2.99) (300)(5.86)^2 = 30,800 \text{ in-lb} \]
4) Compute $R_P$ and find $P$:

$$C_0 = \left( \frac{4}{6} \right)^3 = \left( \frac{2}{3} \right)^3 = 0.483$$

$$R_p = R \cdot C_0 = (0.330) (0.483) = 0.160$$

Enter Figure 4-B @ $R_p = 0.170$ and read off $P'$ for:

$$\frac{S}{h} = 0.25$$

$$P' = 0.554$$

$$P = P' \cdot C_D = (0.554)(300)(5.86) = 974 \text{ lbf}.$$ 

5) Comparing the results with Example 4:

- Depth: -2.7% difference
- Bending moment: 2.7% difference (A328 steel)
- Tie-rod pull: -21% difference

The significance of the tie-rod load can be examined by comparing the required diameters.

Design chart values:

$$T = (974)(1.5) = 7509 \text{ lbf}$$

$$A_{req} = \frac{7509}{22,000} = 0.332 \text{ in}^2$$

$$d = \sqrt{\frac{4A}{T}} = \left[ \frac{(4)(0.332)}{7509} \right]^\frac{1}{2} = 0.69$$

Hand calculation:

$$T = 9250 \text{ lbf}$$

$$A_{req} = \frac{9250}{22,000} = 0.420 \text{ in}^2$$

$$d = \left[ \frac{(4)(0.420)}{9250} \right]^\frac{1}{2} = 0.73$$
EXAMPLE G: ATERBERG LIMIT TESTS PERFORMED ON THE CLAY FRACTION OF THE SUBGRADE MATERIAL IN EXAMPLE 9 REVEALED:

- WATER CONTENT: \( W = 40\% \)
- LIQUID LIMIT: \( LL = 55\% \)
- PLASTIC LIMIT: \( PL = 34\% \)

1) **DETERMINE PLASTICITY INDEX (LIQUIDITY INDEX):**

\[
P_I = LL - PL = 55 - 34 = 21 \\
IL = \frac{W - PL}{P_I} = \frac{40 - 34}{21} = 0.29
\]

2) **DETERMINE ACTIVITY (60% CLAY):**

\[
x = \frac{P_I}{\%\text{CLAY}} = \frac{21}{60} = 0.35
\]

The indicators suggest that this clay soil will cause no troubles (low activity, low plasticity and low liquidity index.) See Wu, 1976.

3) **THE DRAINED STRENGTH CAN BE ESTIMATED AS:**

\[
q = 24^\circ \quad \text{(Wu, 1976)}
\]

4) **RECALCULATE PENETRATION DEPTH:**

\[
x_1 = \frac{x_2^3 - x_3^3}{x_3^3} = \frac{(100)(4)^3 - (57.6)(8)^3}{(47.6)(12)^3} = 0.434
\]

\[
C_9 = \left(\frac{HW}{\eta} \right)^2 \left(\frac{HA}{4-HA} \right) = \left(\frac{6}{12} \right)^2 \left(\frac{7}{10} \right) = 0.0389
\]

\[
P_0 = R \cdot C_9 = (0.434)(0.0389) = 0.0338
\]

Enter Figure 4-10 @ RO = 0.0328 and read off \( C' = 0.719 \)

\[
D = C' \cdot H = (0.719)(12) = 8.62 \text{ ft}
\]
7) RECALCULATE BENDING MOMENT

\[ C_M = \left( \frac{D\cdot H_A}{H-H_W} \right) = \left[ \frac{(8.43)(2)}{(12)(5)} \right] = 0.179 \]

\[ R_M = R\cdot C_M = (0.436)(0.179) = 0.0780 \]

ENTER FIGURE 4-12 @ RM = 0.0780 AND READ OFF M FOR "SAND FILL/PHI = 26"

\[ M = 0.100 \]

FOR \( L = \frac{2}{3} \), \( H = H_W = \left( \frac{2}{3} \right)(8.43) + 10 = 15.75 \)

\[ M = M'L^3 = (0.098)(47.4)(15.8)^3 = 18,400 \text{ in-lbs./ft.} \]

4) RECALCULATE TIE-ROD PULL:

\[ C_0 = C_M = 0.179 \]

\[ R_0 = R\cdot C_0 = RM = 0.078 \]

ENTER FIGURE 4-11 @ R0 = 0.0780 AND READ OFF P FOR "SAND FILL/PHI = 26"

\[ P = 0.0334 \]

\[ P = P'y \cdot L^2 = (0.0334)(100)(15.8)^2 = 534 \text{ lb./ft.} \]
EXAMPLE #7: DETERMINE THE DIAMETER OF THE TIE-ROD BASED UPON THE LOAD GIVEN IN EXAMPLE #1:

1) GIVEN: $T = 7,500$ kips

2) $d = \sqrt{\frac{4T}{\pi f_L}}$  \hspace{1cm} (sec. 5-17)
   
   a) Choose $f_L = 1.2$

   b) $f_L = 0.60 f_u$

   \hspace{1cm} = (0.60)(30,000)

   \hspace{1cm} = 18,000$ psi

   c) $d = \sqrt{\frac{(4)(7,500)(1.2)}{\pi (18,000)}}$

   \hspace{1cm} = 0.729$ in.

3) ADD 7/8 IN. FOR FRESH WATER
   \hspace{1cm} (d = 0.895$ in., use 7/8 in.)

   ADD 1/4 IN. FOR SALT WATER
   \hspace{1cm} (d = 0.978$ in., use 1 in.)

4) USE A 7/8 IN. HOLE FOR THE TIE-ROD BEARING PLATE,
   A 1/32 IN. HOLE FOR THE WALE AND PILE (WOOD WALES)

   USE A 1/8 IN. HOLE FOR THE TIE-ROD PASSING THROUGH STEEL SHEET PILES.
EXAMPLE 8-8: GIVEN THE LOADS IN EXAMPLE 8-1, DESIGN A WAILE FOR STEEL AND WOOD SHEET PILES.

1) GIVEN: \( P = 1000 \text{ kips}, L = 7.5 \text{ ft} \).

2) DETERMINE MOMENT AND SECTION MODULUS REQUIRED

\[ M = \frac{1}{8} \bar{D} L^2 \]

\[ = \frac{1}{8} \times 1000 \times (7.5)^2 \times 12 \]

\[ = 75,000 \text{ in} \cdot \text{lb} \]  

\[ s = \frac{M}{\bar{D}} \]  

\[ = \frac{75,000}{22,000} \]  

(A36 STEEL)  

\[ = 3.41 \text{ in}^3 \]  

USE 2 EA. C4 x 5.4 CHANNELS

\[ s = 1.93 \text{ in}^3 \]  

PER CHANNEL X 2 CHANNELS  

(TBA 5-3)  

\[ = 3.86 \text{ in}^3 > 3.41 \text{ in}^3 \]

3) \( s = \frac{P}{F_0} = \frac{75000}{2000} \)  

\[ = 37.5 \text{ in}^3 \]  

4) USE 4 x 10 MEMBER; \( s = 54.63 \text{ in}^3 \)  

(TBA 5-46)

A 3 x 10 SECTION HAS ADEQUATE SECTION MODULUS, HOWEVER A 1/32 N. HOLE LEAVES ONLY 0.8 IN. OF WOOD BETWEEN BOLT AND EDGE OF WAILE.
EXAMPLE 9: DETERMINE THE SIZE AND NUMBER OF NAILS
REQUIRED TO FASTEN THE PILES DESIGNED
IN EXAMPLE 1 TO

1) GIVEN: P = 1000 ft/lb,
   t = 2 3/8 in. (3 x 12 nominal)
   Timber material is Southern Pine

2) FIND G:
   G = 0.99

3) TRY A 40 PENNY NAIL (40d)
   \( l = 8 \) in.
   \( p = 83 \) \#/in.
   \( d_e = 3 \text{ in} - 2 3/8 \text{ in.} = 2 3/8 \text{ in.} \)
   \( W_p = 0.22 \)
   \( = (83)(2.375) \)
   \( = 197 \#/\text{nail} \)

4) NUMBER OF NAILS
   \( n = \frac{P}{W_p} \)
   \( = \frac{1000}{197} \)
   \( = 3.08, \text{ use 4 nails/pile} \)

5) TRY A 40d SPIKE
   \( l = 3 \) in.
   \( p = 97 \#/in. \)
   \( W_p = 0.22 \)
   \( = (97)(2.375) \)
   \( = 230 \#/\text{spike} \)
   \( n = \frac{P}{W_p} = \frac{1000}{23} = 43.5, \text{ use 5 spikes/pile} \)
EXAMPLE #10: DETERMINE THE NAIL SIZE REQUIRED TO FASTEN SHEET PILES TO AN OUTSIDE WALE.

1) GIVEN: $t = 2\frac{3}{8}$ in.

2) $\phi = \frac{9}{32} \times \frac{\phi}{(\phi/3)} (2.625)$
   \[ = 4.375 \text{ in.} \]

3) USE 30d NAIL ($\phi = 4\frac{1}{2}$ in.)
   \[ \text{(Tab 3-7)} \]

EXAMPLE #11: DESIGN A BEARING PLATE FOR THE TIE-ROD DESIGNED IN EXAMPLE #7

1) GIVEN: $T = 7500$ ft

2) DETERMINE AREA REQUIRED

\[ A = \frac{T}{\phi^2} \]
\[ = \frac{7500}{(454)^2} \]
\[ = 12.48 \text{ in.}^2 \]

3) SIZE THE PLATE

\[ A = b h \cdot A_{ho} \]
\[ A = \frac{(3\frac{1}{2})(1.25)^2}{3\frac{1}{2} \times 5} \]
\[ h = \frac{(16.48 + 9)}{3.5} \]
\[ h = 4.99 \text{ in.} \]

USE 3.5 IN. PLATE

4) DETERMINE $F_p$; N AND $\phi$

\[ F_p = \frac{T}{(454 - A_{ho})} \]
\[ = \frac{7500}{(3.5)(3.5) - (0.99)} \]
\[ = 234 \text{ ft} \]

\[ N = \frac{\phi}{2} (b - 2A_{ho}) \]
\[ = \frac{\phi}{2} (3.5 - 1.25) \]
\[ = 1.19 \]

\[ \phi = \sqrt{\frac{3 F_p}{N^2}} \]
\[ = \sqrt{\frac{3(234)^2}{(1.19)^2}} \]
\[ = 0.30 \]

USE 2.5/8 x 3.5 x 3
EXAMPLE #12: A UNIFORMLY DISTRIBUTED SURCHARGE LOAD OF 200 lb. PER SQ. FT. IS TO BE PLACED UPON THE BACKFILL OF THE SITE DESCRIBED IN EXAMPLE #1. DETERMINE THE REQUIRED PENETRATION DEPTH, TIE-ROD LOAD, AND MAXIMUM BENDING MOMENT.

1) GIVEN: \( q = 200 \text{ lb/ft}^2 \)

GEOMETRY AND SOIL CONDITIONS GIVEN IN EX. #1

2) THE EFFECT OF THE UNIFORMLY DISTRIBUTED SURCHARGE IS A RECTANGULAR STRESS DISTRIBUTION IN EACH SOIL LAYER, AS SHOWN IN FIG. 4-2. COMPUTE THE RESULTING MOMENTS ABOUT THE TIE-ROD AND ADD TO THE MOMENTS COMPUTED IN EXAMPLE #1.

\[
K_1: (2/3) (2 / 2 - H_0) + (K_2 q_2) (2 / 2 - H_0 + H_0) + (K_3 q_3) (2 / 2 - H_0 + H_0) + (19,400 + 3,360 D - 7/3 D^2 - 58.8 D^3) = 0
\]

\[
K_2: (3/4) + (38.2 D^2 - 74.4 D) + (10,400 - 3360 D - 7/3 D^2 - 58.8 D^3) = 0
\]

\[
K_3: 0.070 + 41,200 - 675 D^2 - 58.8 D^3 = 0
\]

\( D = 0.2' \)

3) SUM MOMENTS ABOUT \( 2/3 D \) TO DETERMINE TIE-ROD LOAD

\[
(2/3) (2 / 2 - H_0 - 2/3 D) + (2/3) K_1 (2 / 2 - 2/3 D) + (2/3) K_2 (2 / 2 - 2/3 D) + (2/3) K_3 (2 / 2 - 2/3 D) + (2/3) (4.14 D) + (2/3) (2 / 2 - 2/3 D - H_0) = 0
\]

\[
3100 + 3010 + 9990 + 3340 + 170 = 14.1 P = 0
\]

\( P = 1810 \text{ lb/ft.} \)

4) FIND POINT OF ZERO SHEAR; \( x \approx \) FT BELOW THE WATER LEVEL (2.1):

\[
P = (2 / 2 K_1 (2 / 2 + 2 / 2) x_2 - (2 / 2 K_2 x_2 - K_2 (2 / 2) x_2) x = 0
\]

\[
7.68 x^2 - 154 x - 1175 = 0
\]

\[
x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}
\]

where \( a = 7.68 \)
\( b = 154 \)
\( c = 1175 \)

\( x = 5.3 \) FT below \( c \).
5.) FIND MAXIMUM MOMENT

\[ M_{\text{max}} = \frac{2}{\pi} (2, \pi + x - H_d) - \frac{1}{\pi} k_a \pi \left( \frac{3 \pi}{2} + x \right) - k_2 \pi \left( \frac{3 \pi}{2} + x \right) - \frac{1}{\pi} k_a \pi \left( \frac{3 \pi}{2} + x \right) - \frac{1}{\pi} k_2 \pi \left( \frac{3 \pi}{2} + x \right) \]

\[ = 11,930 - 1010 - 440 - 2470 - 330 \]

\[ = 6680 \text{ ft.-lb./ft.} \]

6.) COMPUTE \( \alpha = \phi / \beta \):

\[ \alpha = \frac{H_a}{H_0} = \frac{12}{18+6.2} = 0.66 \]

\[ \frac{H_a}{H_0} = \frac{2}{12} = 0.17 \]

7.) THE LOAD:

\[ f_c = 0.95 \]  

\[ P = (0.95) (1910) = 1835 \text{ lb.} \]

8.) COMPUTE REDUCTIONS FROM OPERATING AND STRUCTURAL CURVES FOR WOOD, AS IN EX. 9:

\[ T_{\text{max}} = \left( \frac{12}{12} \right) \left( \frac{18}{2} \right)^2 = 12.2 \]

\[ T = 4.56 \]

\[ M = Td^3 = (2.95) (18.2)^3 \]

\[ = 27,910 \text{ in.-lb.} \]

**EXAMPLE 13:** USE THE SIMPLIFIED METHOD FROM THE PRECEDING SITUATION

1.) DETERMINE THE EQUIVALENT HEIGHT OF SOIL, \( H_a \), AND ADD THIS TO THE FREE STANDING WALL HEIGHT, \( H' \):

\[ H_a = \frac{200}{100} = 2 \text{ ft.} \]

\[ H = 12 + 2 = 14 \text{ ft.} \]

2.) FROM EX. 9, \( \frac{H}{H'} = 0.436 = D' \)

\[ D = DH' = (0.436)(14) = 6.1 \text{ ft.} \]

3.) FROM EX. 9, \( M' = \frac{H_0}{\frac{12}{3}} = 0.103 \)

\[ L = \frac{3}{2} D + H - H_a = (\frac{3}{2})(6.1) - (4) - (2) = 16.1 \text{ ft.} \]

\[ M = M' \times L^3 = (0.103)(60)(16.1)^3 = 26,800 \text{ in.-ft.} \]

4.) FROM EX. 9, \( P' = \frac{P}{5} = 0.0622 \)

\[ P = P' \times L^2 = (0.0622)(100)(16.1)^2 = 1612 \text{ lb.} \]
Example # 14: Determine the penetration depth, bending moment, and tie-rodd load for the wall in the previous example, instead of a point load, consider a continuous foundation footing 10 ft. from the sheet piles with a load of 5 kips/ft.

1) Given: $G = 5000 \text{ kips/ft.}$
   $X = 10 \text{ ft.}$
   Geometry and soil conditions remain unchanged.

2) $M = \frac{X}{H} = \frac{10}{1.2} = 8.33$

   $PH = \frac{0.64 \times \frac{2}{3}}{(0.63)^2 - 1} = \frac{(0.64)(5000)}{(0.63)^2 - 1} = 1890 \text{ kips/ft.}$
   (Fig. 5-16)

3) Extrapolate $L$ from Figure 5-16. For $M = 0.83$,
   $L = 0.434 = 5.16 \text{ ft.}$

4) Sum moments about tie-rodd, as in previous example:
   $PH (H-L-H) = (1890)(12-5.16-2) = 9150$
   $(9150) - (14,400) = 33,600 - 9150^2 - 38.80^3 = 0$
   $D = 0.2$

5) Sum moments about 3/4 D. PH acts @ (L - 3/4 D) from 3/4 D:
   $PH (L - \frac{3}{4} D) = (1890)[(12-\frac{3}{4}(4.2)] = 17,940$
   $(17,940) - (3300 - 3340 - 1440) = 14.1 P$
   $P = 1180 \text{ kips/ft.}$

6) Find point of zero shear:
   $C = \frac{1}{2} X = 5.17$
   $PH - P = 313$
The value of C is positive, which indicates that the shear force diagram changes abruptly (at the point of PH) from positive to negative. This is where the maximum moment will occur.

\[ x = \frac{W - L - 5}{2} = 2.84 \text{\' below the water level.} \]

7) Find \( M_{\text{max}} \)

\[ M_{\text{max}} = (1800)(4.84) - (223)(417) - (60)(-413) = 7310 \text{ ft} \cdot \text{lb/ft.} \]

8) Compute the tie-rodd load

\[ \theta = 3/18.2 = 0.16\quad \alpha = 3/18.2 = 0.16, \quad A_e = 0.95 \quad \text{(Fig. 2-7b)} \]

\[ P = 2 e P_0 = (0.95)(1800) = 1710 \text{\#/ft.} \]

9) Compute bending moment reductions

\[ T_{\text{max}} = (12)(7310)/(18.2)^3 = 14.6 \]

Generating new \( T_0 \) values using the same reduction factors will give

\[ T = 5.90 \]

\[ M = T \cdot H_0^3 = (5.90)(18.2)^3 = 35,500 \text{ in.} \cdot \text{lb/ft.} \]
EXAMPLE 4.15: USE THE SIMPLIFIED METHOD FROM THE PRECEDING SITUATION.

1) DETERMINE AN EQUIVALENT HEIGHT OF SOIL FOR PH AND ADD THIS TO THE FREE STANDING WALL HEIGHT, H:

\[ H_{eq} = \frac{PH}{X_1(H-L)} = \frac{18.9}{(100)(12.5)} = 2.77' \]

\[ H = 12 + 2.77 = 14.8' \]

2) FROM EX. 4.3, \( \frac{B}{H} = 0.436 = D' \)

\[ D = D'H = (0.436)(14.8) = 6.5' \]

3) FROM EX. 4.3, \( M' = \frac{M}{\bar{X}_4} = 0.103 \)

\[ L = \frac{4}{3} D - H - HA = (\frac{4}{3})(6.5) - (14.8) - (2) = 17.1' \]

\[ M = M' \frac{L^3}{3} = (0.103)(60)(17.1)^3 = 31,100 \text{ in} ^3 / \text{ft}^2 \]

4) FROM EX. 4.3, \( \frac{P}{L^2} = 0.0622 \)

\[ P = \frac{P}{L^2} = (0.0622)(100)(17.1)^2 = 1820 \text{ ft} \]
EXAMPLE 10: A 10,000 lb. LOAD IS TO BE LOCATED 3 ft. FROM THE SHEET PILES OF THE WALL GIVEN IN EX. #1.
Determine the required penetration, depth, the rod load, and maximum bending moment.

1) GIVEN: \( q_0 = 10,000 \) lb
   \( x = 3 \) ft
   GEOMETRY AND SOIL CONDITIONS GIVEN IN EX. #1

2) \( m = \frac{x}{H} = \frac{3}{10} = 0.3 \)
   \( P_H = 0.45 \left( \frac{3}{v} \right) = 450 \) lb

3) INTERPOLATE \( L \) FROM FIG 5-19
   \( L = 0.56H = 6.48 \) ft.

4) SUM MOMENTS ABOUT THE ROOD:
   DH acts at 5.4 ft. from DL or \( (H-L-HA) = 3.92 \) ft. from the rod.
   ADD \( DH \) \( (H-L-HA) \) TO MOMENTS COMPUTED IN STEP 4, EX. #1:
   \( 450 \left( 3.92 \right) + 10,400 - 3900 - 7130^2 - 58.80^3 = 0 \)
   \( D = 3.5 \) ft.

5) SUM MOMENTS ABOUT 2/3 D. DH acts at a distance \( (L - \frac{2}{3}D) = 13.7 \) ft. from 4/3 D
   ADD DH \( (L - \frac{2}{3}D) \) TO MOMENTS COMPUTED IN STEP 5, EX. #1:
   \( 450 \left( 13.7 \right) - (2900 + 3110 - 4780 + 1140) = 13.7 \)
   \( D = 1500 \) ft.

6) FIND POINT OF ZERO SHEAR AS IN STEP 6, EX. #1, EXCEPT THAT:
   \( c = \frac{1}{2}kD, \frac{x}{L} + P_H - D = 323 \)
   \( x = 7.10 \) ft. BELOW THE WATER LEVEL (i.e., BELOW 4.)
7) FIND THE MAXIMUM MOMENT, AS IN STEP 7, EX. #1 INCLUDING THE MOMENT CAUSED BY PH (L + 2, X = H)

\[ M_{\text{max}} = -(450)(6.48 - 4 \times 7.10 - 12) + (1500)(9.10) - (223)(8.45) - (910) - (25.00) \]

\[ = 5740 \text{ ft. lb./ft.} \]

8) COMPUTE THE TIE-ROD LOAD, AS IN STEP 8, EX. #1:

\[ \beta = \frac{9}{17.5} = 0.51, \Delta = 12/19.5 = 0.61, \frac{X}{\beta} = 1.0 \quad (\text{FIG. 2-17b}) \]

\[ P = \frac{\beta}{\alpha} \times 1500 = \frac{1.0}{0.61} \times 1500 = 2459 \text{ lb./ft.} \]

9) COMPUTE BENDING MOMENT REDUCTION AS IN STEP 9, EX. #1:

\[ \frac{P_{\text{max}}}{(12)} \times \frac{(5740)}{(17.5)^2} = 12.90 \]

GENERATE NEW \( P \) VALUES USING THE SAME REDUCTION FACTORS AS IN EX. #1.

\[ P = 3.48 \]

\[ M = \frac{P \times H^3}{3} = (3.48)(17.5)^3 = 18,450 \text{ lb. ft./ft.} \]

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EXAMPLE #17: USE THE SIMPLIFIED METHOD FOR THE PRECEEDING SITUATION.

1) DETERMINE AN EQUIVALENT HEIGHT OF SOIL FOR PH AND ADJUST THIS TO THE FREE STANDING WALL HEIGHT, H:

\[ H_{eq} = \frac{P \times H}{2 \times (H - L)} = \frac{450}{(100)(12 - 0.48)} = 0.32 \]

\[ L = 12 - 0.32 = 12.22 \]

2) FROM EX. #3, \( \frac{P}{H} = 0.436 \times D' \)

\[ D = D' \times H = (0.436)(12.22) = 9.59 = 9.5' \]

3) FROM EX. #3, \( M' = \frac{M}{L^2} = 0.103 \)

\[ L = \frac{3}{2}D = \frac{3}{2} \times H = (\frac{3}{2})(9.5) = 14.2 \quad (2) = 14.5 \]

\[ M = M' \times L^3 = (0.103)(50)(14.5)^3 = 19,800 \text{ in. lb.} = \]

4) FROM EX. #3, \( \frac{P'}{L^2} = 0.0422 \)

\[ P = \frac{P'}{L^2} = (0.0422)(100)(14.5)^2 = 350 \text{ lb./ft.} \]
EXAMPLE 15: DESIGN A 2 MEMBER SPlice FOR AN INSIDE WALE HAVING THE DIMENSIONS AND LOADS AS IN EXAMPLE #8.

1) GIVEN: WALE IS 4 x 10
   M = 75000 k-im-lb.

2) SELECT Lb, FIND V
   TRY Lb = 24 in.

   \[ V = \frac{1}{2} - \frac{3Lb}{4} \]

   \[ = \left( \frac{7500}{2} \right) - \left( \frac{1000}{4} \right) \left( \frac{24}{12} \right) \]  \hspace{1cm} \text{(Eq. 5-23)}

   \[ = 3250 \text{ ft} \]

3) USE THE SAME SIZE MEMBER AS THE WALE FOR THE SPICE PLATE, SELECT d AND d BASED ON b
   FOR 4x10, b = 3 3/8
   d = 1 in. \hspace{1cm} \text{(Tab 5-8)}
   FOR 2-MEMBER JOINTS OF EQUAL b, USE \( \frac{b}{2} \)
   \( \frac{b}{2} = 1 \text{ in.} \)

4) NUMBER OF BOLTS REQUIRED 3 EACH END
   \[ n = \frac{3250}{310} = 4.01 \] \hspace{0.5cm} \text{USE 2 ROWS OF 2 BOLTS}

5) DETERMINE DISTANCE REQUIREMENTS FOR BOLT DIAMETER OF 1 in. \( \frac{1}{4} = 3.225/4 = 3.225 \)
   EDGE = 4 in. \hspace{1cm} BOLT SPACING = 4 \hspace{1cm} \text{(Tab 5-10)}
   END = 1/2 in. \hspace{1cm} ROW SPACING = 3 1/4

6) THE DISTANCE REQUIREMENTS FOR EDGE AND ROWS OF BOLTS EXCEED THE DIMENSION OF THE MEMBER. REPEAT STEPS 2 THROUGH 5, USING 4 x 2 INCHES. THIS WILL PERMIT OVERALL LENGTH OF THE SPICE PLATE OF 24 IN. ALLOWING END DISTANCES OF 1 1/2 IN. @ EACH END.
7. \[ v = \left( \frac{7500}{2} \right) - \left( \frac{1000}{2} \right) = 3312 \]

For \( \frac{3}{8} \) in. bolt, \( q = \frac{1000}{2} = 600 \) 

For \( \frac{3}{8} \) in. bolt, \( \frac{b}{d} = 5.5 \)

End = 0.438, Use 1”

Row spacing: \( \frac{3}{2} = 3.025 \) (0.025 = 0.5

End = \( \frac{3}{8} ) \times 0.625 = 4.375 \)

Row spacing = \( 4.375 \times \frac{3}{8} = 3.05 \), say 3 in.

b) Use 6 each \( \frac{3}{8} \) in. bolts in each end
EXAMPLE 19: DESIGN A 3 MEMBER SPICE USING THE DATA FROM THE PREVIOUS EXAMPLE.

1) GIVEN: WALE IS 4 x 10
   M = 75,000 IN-LB

2) USE SAME L3 AS PREVIOUS EXAMPLE
   FOR L3 = 21 IN., v = 3312

3) SELECT A SPICE DIMENSIONS:
   THE SECTION OF EACH PLATE MUST BE 1/2 THE REQUIRED.
   REQUIRED S = 37.5 IN$^3$; v2 = 18.75
   USE 2 x 10 (s = 24.44 > 18.75) (TAB 5-14)
   a = 1.25
   (FIG. 5-11)

   TAKE b = 2a = (2)(1.25) = 3.25
   USE L = b = 3.0 IN TABLE 5-6

4) SELECT A AND G
   FOR 5/8 IN. BOLT, G = 1000

   v = 3312
   1000 = 3.31 :: USE 2 ROWS OF 2 BOLTS

5) DETERMINE SPACING FOR L/2 = 3/8 = 4.3
   EDGE = 2.5
   END = 0.328
   BOLT SPACING = 2.5
   ROW SPACING = (4.25 + 2) = 2.656

6) USE 4 EA. 5/8 IN. BOLTS @ EACH END

\[
\begin{array}{cccc}
\text{EDGE} & \text{BOLT} & \text{EDGE} & \text{BOLT} \\
2.5 & 5/8 & 2.5 & 5/8 \\
3.3 & 5/8 & 3.3 & 5/8 \\
21'' & 17'' & 21'' & 17''
\end{array}
\]
EXAMPLE 42C: DETERMINE THE FASTENERS REQUIRED FOR THE STEEL SHEET PILE WALL IN EXAMPLE 41 AND THE WALES IN EXAMPLE 48.

1) GIVEN: PS25 SECTION
   3 x 5 WALES
   \( P = 1000 \) \( \#/\) FT.

2) DETERMINE THE NUMBER OF BOLTS REQUIRED FOR AN INSIDE WALE.

   \( W = 15 \) IN.
   SELECT A \( \frac{5}{8} \) IN. BOLT (SMALLEST BOLT) (TAB 5-2)

   \[ n = \frac{4Pw}{\sigma A} \]

   \[ = \frac{(4)(1000)(15)}{(0.425)(\frac{5}{8})(40000)} \]

   \[ = 0.102 \]

   USE 1 BOLT EVERY OTHER SECTION

3) DIMENSION THE FIXING PLATE

   USING PIPE SEPARATORS 2 IN. LONG GIVES A SPAN BETWEEN CHANNELS OF 2 IN.

   USING 1 EA. \( \frac{5}{8} \) IN. BOLT EVERY OTHER SECTION EXERTS A TENSILE FORCE IN THE BOLT OF

   \[ F = 2Pw = (2)(1000)(\frac{15}{2}) \]

   \[ = 2500 \] \( \# \)

   THE MOMENT IN THE FIXING PLATE IS

   \[ M = \frac{1}{2} PL = \left(\frac{1}{2}\right)(1000)(2) \]

   \[ = 1250 \) IN. \( \# \).
\[ t = \sqrt{\frac{GM}{b_f}} \]

for \( b = 3 \) \text{ in.}

\[ t = \sqrt{\frac{(2)(1250)}{(4)(22,000)}} = 0.29 \text{ in.} \]

\text{USE } t = 3 \text{ in.}

\text{EDGE DISTANCE } = 1.25 d = (1.25)(\frac{3}{8}) = 0.78 \text{ in.}

\text{REQUIRED MINIMUM DIMENSION IS TWICE THE EDGE DISTANCE PLUS THE BOLT HOLE. THE BOLT HOLE IS } \frac{3}{8} \text{ IN. LARGER THAN THE BOLT.}

\[ d = (2)(0.78) + (\frac{3}{8}) + (\frac{1}{8}) = 2.31 \text{ in. MIN.} \]

\text{USE } 3\frac{1}{8} \times 3\times 3
EXAMPLE 7.2: DESIGN SPICE PLATES FOR THE WALLS DESIGNED IN EXAMPLE #8.

1) GIVEN: \( m = 75000 \text{ kN} \cdot \text{m} \)
   \( C4 \times 5.4 \text{ CHANNELS} \)

2) THE PLATE WIDTH IS LIMITED BY THE FLANGE-TO-FLANGE WIDTH OF THE CHANNELS, EDGE DISTANCE AND BOLT HOLE DIAMETER.

   \[ b = d - 2g \quad (\text{TAB 5-3}) \]

   \[ = (4.00) - (2)(0.196) \]

   \[ = 3.44' \]

   FOR A \( \frac{3}{8} \text{ in.} \) BOLT, THE EDGE DISTANCE AND BOLT HOLE REQUIREMENTS GIVE A MINIMUM \( b \) OF 2.31 IN. (EX. #13)

   \( \therefore \) USE \( b = 3\frac{1}{4} \text{ in.} \)

3) \( S = \frac{m}{L^2} = 3.44 \text{ kN} \cdot \text{m}^3 \) (FROM EX. #8) \( (\text{EQ. 9-9}) \)

   \[ S = \frac{1}{2} gb^2 \] (BENDING ABOUT STRONG AXI) \( (\text{EQ 9-10a}) \)

   \[ t = \frac{6S}{b^2} = 1.74 \text{ in. FOR 2 PLATES (TOP & BOTTOM CHANNELS)} \]

4) USE A 12 IN. LONG PLATE, MINIMUM EDGE DISTANCE IS 1.502, OR 0.94 IN. FOR \( \frac{3}{8} \text{ in.} \) BOLTS. USE \( L = 10 \text{ in.} \)

   \[ V = \frac{T}{2} = \frac{PLt}{4} \quad (\text{EQ 9-23}) \]

   \[ = \left( \frac{2500}{2} \right) - \left( \frac{1000}{4} \right) \left( \frac{10}{2} \right) \]

   \[ = 3542 \text{ kN} \]

5) CAPACITY OF A \( \frac{3}{8} \text{in.} \) BOLT IN SINGLE SHEAR IS

   \[ F_s = (15,000)A \times (15,000)(\frac{3}{8})^2 = 4600 \text{ kN} \]

   CAPACITY IN DOUBLE SHEAR IS \( 9200 > 3542 \text{ kN} \)

   \( \therefore \) USE 1 EACH \( \frac{3}{8} \text{ in.} \) BOLT 6 IN. FROM THE END.

   USE 2 \( 1\frac{1}{2} \times 3\frac{1}{2} \text{ in.} (2 \text{ EACH}) \)
EXAMPLE 22: GIVEN THE CONDITIONS OF EXAMPLE #1, DESIGN A CONTINUOUS DEADMAN ANCHORAGE.

1) GIVEN: $L = 4 \text{ ft}$, $V_e = 1000 \text{ kip}$, $K_p = 3.00$
   $H_a = 2 \text{ ft}$, $V_2 = 50 \text{ kip}$, $K_a = 0.408$

2) SELECT $h_1 = 1 \text{ ft}$, $K_p' = K_a' = 2.59$

3) LET $h_w = h_1$, ALTHOUGH THE TOP ROOF IS LOCATED SLIGHTLY ABOVE THE WATER LINE.

4) COMPUTE THE RESULTANT FORCES ACTING ON THE ANCHORAGE (FIGURE 5-25)

a) NET FORCES:

   $(K_p' - K_a') V_2 V_l = (2.59)(100)(1) h_l = 259 h_l$

   $\frac{1}{2} (K_p' - K_a') V_2 (h_w - h_l)^2 = \frac{1}{2} (2.59)(100)(2-1)^2 = 129.3$

   $(K_p' - K_a') V_2 (h_w - h_l)(h_a + h_w - h_l) = (2.59)(100)(2-1)(h_l - 1)$

   $= 259 h_l - 259$

   $\frac{1}{2} (K_p' - K_a') V_2 (h_a + h_w - h_l)^2 = \frac{1}{2} (2.59)(100)(h_l - 1)^2$

   $= 77.7 h_l^2 - 155.4 h_l + 77.7$

b) SUM NET FORCES, EQUATE TO THE ROOF PULL/UNIT LENGTH:

   $P = 259 h_l + 129.3 + 259 h_l - 259 + 77.7 h_l^2 - 155.4 h_l - 77.7$

   $1000 = 77.7 h_l^2 + 358.6 h_l - 51.6$

c) SOLVE THE QUADRATIC FOR $h_l$

   $77.7 h_l^2 + 358.6 h_l - 1051.8 = 0$

   $h_l = \frac{-358.6 \pm \sqrt{(358.6)^2 - 4(77.7)(-1051.8)}}{2(77.7)}$

   $= 2.04$, $-6.59$

   USE POSITIVE ROOT, $h_l = 2.04$ ft. 2.00 IS OK.

5) USING THE SAME MATERIAL AS THE WALL REQUIRES NO FURTHER DESIGN. WALES ON THE ANCHORAGE ARE THE SAME AS FOR THE WALES ON THE WALL.

6) ENSURE THAT THE TOE OF THE WALL DOES NOT INTERSECT THE FAILURE WEDGE (FIGURE 5-8).
EXAMPLE #23: USING THE DATA OF EXAMPLE #19, DESIGN A SHORT DEADMAN.

1) GIVEN: \( (P_0 - P_d) = 77.7 \) \( h_r^2 = 358.6 \) \( h_r - 9.8 \)
   \( \xi = 1.00 \) \( K_d = 3.00 \) \( \theta = 15^\circ \)
   \( \xi = 0.60 \) \( K_d = 0.408 \) \( K_d = 0.4 \)

2) SELECT A LENGTH: \( L = 4 \) FT.

3) INCORPORATE THE DATA OF EX. #15 INTO EQ. 5-7:

   \( T_H = L (P_0 - P_d) + \frac{1}{2} K_d (\sqrt{K_d} - \sqrt{K_d^2}) h_r^3 \tan \theta \)

2 VALUES OF \( \xi, \xi \) OVER THE LENGTH \( h_r - h_1 \)

4) SOLVE THE CUBIC BY TRIAL AND ERROR

5) DETERMINE REQUIREMENTS IF AN 6 IN. DIAMETER PILE IS USED

   \( h_r = 3.74' \) \( \omega = 3.75' \)

   \( TSCO = 30.0 h_r^3 + 125.7 h_r - 44.4 + 12.1 - 7.28 (h_r - 1)^3 \)

   \( 0 = 7.28 h_r^3 + 5.16 h_r^2 + 309 h_r - 7922 \)

   \( h_r = 8.4' \) TOO LARGE, 8 IN. PILES ARE NOT FEASIBLE BY THEMSELVES.
REFERENCES


United States Steel (1975), Steel Sheet Piling Design Manual, United States Steel Corp., Pittsburgh, PA, 132 p.

United States Steel (1976), Steel Sheet Piling Handbook, United States Steel Corp., Pittsburgh, PA, 102 p.
