COMPUTER AIDED DESIGN OF SOLDIER PILE AND LAGGING RETAINING WALLS WITH TIEBACK ANCHORS

BY

KEVIN J. D'AMANDA

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A REPORT TO THE GRADUATE COMMITTEE OF THE DEPARTMENT OF CIVIL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING

UNIVERSITY OF FLORIDA

FALL 1991
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Barry "BATman" Mines;
Dave "Mr. FDOT" Horhota;
Dennis Vander Linde "Forces";
Zan "The Zan Man" Bates;
Craig "Cheats at Golf" Dunklenburger;
Dave "Do I still have a desk?" Weinrub;
Guillermo "Just one more year at UF" Ramirez;
Pedro "Lost in Peru" Ruesta;
Tove Feld "and Streams";
and the rest of the crew;

thanks for being an island of lunacy in a sea of sanity.
Lieutenant Kevin J. D'Amanda, Civil Engineer Corps, U.S. Navy, was born and raised in Miami, Florida. He attended Miami Dade Community College and the University of Miami earning a Associate in Arts degree with highest honors in May 1982 and a Bachelor's Degree in Civil Engineering, Magna Cum Laude, in December 1984 respectively. Upon graduation, he was commissioned an Ensign, U.S. Naval Reserve and completed Officer Indoctrination School in Newport, Rhode Island.

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ABSTRACT

Abstract of a Report to the Graduate Committee of the Department of Civil Engineering in Partial Fulfillment of the Requirements for the Degree of Master of Engineering.

COMPUTER AIDED DESIGN OF SOLDIER PILE AND LAGGING RETAINING WALLS WITH TIEBACK ANCHORS

By

KEVIN J. D'AMANDA

FALL 1991

Chairman: Dr. Frank C. Townsend
Major Department: Civil Engineering

Soldier pile and lagging walls are used to support open excavations and restrict lateral movements. They also provide an increased factor of safety to nearby structures and utilities against excessive deformations and loss of bearing capacity. The soldier pile and lagging wall consists of structure H-beams driven into the ground with wood lagging installed between the flanges of the beams to retain the soil. With the use of tieback anchors as bracing, they can provide an unobstructed area for construction.

The design of the soldier pile and lagging wall consists of developing a pressure envelope for the soil conditions and determining the number and location of
The anchors for a given H-beam's section modulus. The pressure envelopes for braced excavations differ from Rankine's active state. A braced excavation deforms more laterally at the bottom of the excavation than the top due to the installation of the anchors. Peck (1969) developed pressure envelopes for braced excavations which can be used for the design of a retaining wall.

A C++ language computer program was developed to optimize the design of the soldier pile and lagging wall. The pressure diagrams for sand and clays developed by Peck and tieback anchor capacity curves from the Federal Highway Administration were used in the program. Also referenced was Naval Facilities Engineering Command, Design Manual 7.2, for flexible wall design. By varying the number and location of the tieback anchors, the wall design may be optimized for given soil conditions and wall requirements.
CHAPTER ONE

INTRODUCTION

1.1 Background

Soldier pile and lagging retaining walls with tieback anchors are used to support open construction excavations and restrict lateral movements of the surrounding soil. The wall provides a factor of safety to nearby structures against any loss of bearing capacity as the result of lateral movements. With the use of tieback anchors, an unobstructed excavation for construction can be provided. Figure 1.1 illustrates a typical soldier pile and lagging wall with tieback anchors. The basic design of the system is as follows:

a. Determine the given boundary conditions indicating soil stratification, water level, slope of the soil behind the wall, and surcharge loads.

b. Compute the lateral earth pressure diagrams for the braced excavation including any pressure diagrams from surcharge loads.

c. Design the components, which include the soldier pile; wale; tiebacks; and lagging, based on the pressure diagrams.
The pressures diagrams for braced cuts differ from lateral earth pressures obtained by Coulomb's or Rankine's theory. Peck (1969) derived lateral earth pressure diagrams for braced cuts in sands and clays which can be used to calculate the maximum moment and reaction forces for the design of the retaining wall system.

Figure 1.1
Tieback Soldier Pile and Lagging Wall for a Cut-and-Cover Station in Philadelphia (FHWA/RD-82/047, 1982)
The basic concept of bracing an excavation is based on the excavation causing the removal of a mass of soil and water from a site. The ground water table may also be lowered outside and below the excavation to accomplish the construction. Consequently, these actions will result in a total stress release and movements in the surrounding soil. A retaining wall is typically installed to control these movements. Satisfactory performance of the wall requires that the excavation periphery not have any excessive movements or deformations. Moreover, deformations of the surrounding soil may be limited so that adjacent structures and utilities are not adversely affected. The factors that influence deformations include the dimensions of the excavation, soil properties, ground water control, time (time excavation open, time a section is unbraced, etc.), support system, excavation and bracing sequence, near-by structures and utilities, and transient surcharge loads. (Lambe and Turner, 1970)

1.2 Computer Program Requirements

The design of soldier pile and lagging retaining walls requires the determination of the number and
location of tieback anchors for a given section modulus of a soldier pile to ensure the pile is not overstressed. This computer program was developed to calculate the maximum moment of a soldier pile, depth of embedment, and reaction forces based on the soil conditions, depth of the excavation, and location of the tieback anchors. By varying the location and number of the anchors, the design of the soldier pile wall may be optimized.

The computer program will also calculate the required anchor capacities, bonded and unbonded length of the tieback anchors, and the section modulus of the wale system based on anchor spacing and soil type. Tieback capacity and length is based on pressure injected tiebacks in cohesionless soils and post-grouted tieback anchors in cohesive soils.

1.3 Computer Language

The computer program was written and compiled in Borland Turbo C++. C was originally developed in the 1970's for use with the UNIX operating system. The definition of C was first presented in The C Programming Language, First Edition by Brian W. Kernighan and Dennis M. Ritchie in 1978. The
American National Standards Institute (ANSI) developed a new standard for the language five years later which resolved ambiguities in it (Turbo C++ Users Guide, 1991). Turbo C++ implements the latest ANSI standard for C. It is manufactured and a registered trademark of Borland International, Inc.
2.1 Braced Excavations

Braced excavation retaining walls are used to support the sides of temporary excavations in various construction applications. The vertical face of the cut is held open by the retaining structure until a permanent structure can be installed. The permanent structure may include the basement of a building, walls of a parking garage, or underground facilities. The braced structure restricts the inward movement of the surrounding soil preventing settlement, collapse of the excavation, and possible bearing capacity failure of nearby structures. Table 2.1 lists the factors to be considered in designing a braced excavation. The most common methods of supporting a temporary excavation are sheetpile walls, drilled-in-place concrete piles, slurry walls, and soldier pile and lagging.

Sheetpiles are driven into the ground prior to excavation, interlocked forming a wall, and then the soil excavated. They may be supported by struts or anchors as required. Drilled-in-place piles may be used with a spacing so that lagging is not required.
Table 2.1  
Steps in Engineering an Excavation  
(Lambe and Turner, 1970)

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<thead>
<tr>
<th>Step No.</th>
<th>Activity</th>
<th>Consideration</th>
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<tr>
<td>1</td>
<td>Explore and test subsoil.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Select dimensions of excavation.</td>
<td>Structure size and grade requirements, depth to good soil, depth to meet stability requirements.</td>
</tr>
<tr>
<td>3</td>
<td>Survey adjacent structures and utilities.</td>
<td>Size, type, age, location, and condition.</td>
</tr>
<tr>
<td>4</td>
<td>Establish permissible movements.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Select bracing and construction sequence.</td>
<td>Local experience, cost, time available, type of wall, depth of wall, type and spacing of bracing, and dewatering sequence.</td>
</tr>
<tr>
<td>6</td>
<td>Predict movements caused by excavation and dewatering.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Compare predicted with permissible movements.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Alter bracing and construction scheme, if needed.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Monitor construction and alter bracing and construction as required.</td>
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Arching of the soil from the lateral pressures developed by the pile will retain the soil across the open spacing (Bowles, 1988). A slurry wall is constructed when concrete is cast-in-placed in a cavity retained open by a slurry liquid. After the concrete cures, the soil next to the wall is excavated. Soldier pile and lagging uses steel H-piles driven into the ground prior to the actual excavation. Lagging is placed between the piles as the ground is excavated. The lagging may be either wood or steel members. Anchors or struts are used to support the wall as the excavation proceeds.

If present, ground water acts against the wall and thus contributes to the stresses which must be carried by the wall. It also influences the effective stress of the soil. The total force felt by the wall is a combination of the hydrostatic force and the effective soil stress. If flowing water occurs, a seepage analysis should be made. Factors which must be considered in a seepage analysis includes the permeability of the insitu soil, leakage through the wall, flow parallel to the wall, excess pore pressures generated by changes in total stresses, seepage forces, and the time the excavation will be open and hence the
degree of saturation. The actual pore water pressures generated will typically be less than static pressures. (Lambe and Turner, 1970)

2.2 Soldier Pile and Lagging

The procedure for constructing a soldier pile wall is to drive the H-piles into the ground prior to any excavating. The piles are driven with the flanges parallel to the proposed cut. They are usually spaced between four and ten feet apart. When they have been driven down to the desired depth (typically five to ten feet beneath the proposed excavation bottom when in soil), the excavation begins in stages. The first stage of the excavation is made to the location of the uppermost strut or anchor. Timber lagging, cut to fit between the webs of adjacent soldier piles, is placed in back of the front flanges of the piles. They are set one piece of lagging on top of the other with only a small spacer between them. Straw or a geotextile may be placed between and behind the lagging to reduce seepage through the wall. Once the lagging is set down to the first strut level, a horizontal wale is installed against the piles and the struts or anchors placed at the desired spacing. The excavation then
proceeds to the next strut level, with the process continuing until the final excavation is reached. (Keorner, 1984)

Primary components of a soldier pile and lagging wall are as follows:

1. Soldier piles which may be either steel H-beams, steel tubular pipes, concrete piles, or cast-in-place concrete piles.

2. Support system of braced struts or anchors. Anchors may be cast-in-place deadman, piles used as anchors, sheetpile wall sections, or tieback anchors.

3. Wales which distribute the anchor force as a line load between the soldier piles. They are usually structural steel sections.

4. Wood or metal lagging which supports the soil between the piles. (Boghrat, 1989)

Advantages of using soldier pile and lagging walls include fewer piles, the lagging does not have to be extended below the excavation bottom, and the soldier piles can be driven easier in hard ground than can sheetpile sections. By varying the spacing of the soldier piles, underground utilities may be avoided. Also the use of heavy sections for piles will allow wider spacings of wales and bracing. (Merritt, 1976)
2.3 Tieback Anchors

Temporary tieback anchors are used to support the sides of deep excavation retaining structures. Tieback systems deform less than strut braced excavations because: (a) a force at or above the active earth pressure is locked off in every tieback, (b) tieback construction does not require over excavation, (c) tiebacks are not subject to significant temperature-caused deformations or loads, and (d) rebracing is not required for tieback walls. When the depth of the excavation exceeds fifteen to twenty feet and the width exceeds sixty feet or when obstructions significantly impact construction, tieback walls are usually less expensive than strut braced support systems. Tieback walls provide a clean open excavation for construction. Internally braced walls interfere with excavations, concrete work, structural steel placement, and backfilling. (FHWA/RD-82/047, 1982)

Some disadvantages of a tieback anchor system may include obtaining permission for the placement of the anchors in the property of a municipality or a private owner. The location of the anchors may be outside the boundaries of the project where soil properties were not obtained. Achieving a satisfactory anchorage
capacity in soft clays or submerged sands may also be difficult to achieve. (Clough, 1972)

The capacity of tieback anchors is dependent on the size and shape of the anchor, tendon type and size, insitu soil properties, and installation and grouting method of the anchor. Design of a tieback system should include the following:

a. a tieback feasibility evaluation,

b. an evaluation of the risk and consequences of failure,

c. the selection of a tieback type,

d. the estimation of the tieback capacity,

e. determination of the unbonded and total tieback length,

f. selection of a corrosion protection system,

g. selection of a tieback testing procedure,

and

h. establishment of an observation and monitoring system. (FHWA/RD-82/047, 1982)

Federal Highway Administration report number FHWA/RD-82/047, Tiebacks, provides detailed guidance and design procedures for tiebacks.
3.1 Lateral Earth Pressures in Braced Excavations

When sufficient yielding of a retaining wall occurs, the lateral earth pressure can be approximated by Coulomb's or Rankine's theory. However, braced excavations yield differently than conventional retaining walls. Figure 3.1 depicts the different deflections of the two wall types. The deformation of a braced wall gradually increases with the depth of excavation. The variation of the amount of deformation will depend on the type of the soil, depth of the excavation, and construction of the wall.

Figure 3.1
Nature of Yielding of Retaining Wall and Braced Cut (Das, 1990)
At the top of the excavation, deformations are small thus the lateral earth pressure approaches the at rest condition. At the bottom of the excavation, the deformations are greater, but the lateral earth pressure will be lower than Rankine's active earth pressure. Therefore the distribution of lateral earth pressure deviates from the usual linear distribution (Das, 1990). This is illustrated in Figure 3.2. The total force exerted against the wall may be 10-15% greater than active condition. The state of stress behind a braced excavation has been described as an arching active condition (Lambe and Whitman, 1969 and Cernica, 1982).

![Figure 3.2 General Pressure Distribution on Braced Excavation (Cernica, 1982)]
The pressure envelopes proposed by Terzaghi and Peck (1967) and as recommended by NAVFAC DM-7.2 (1982) are assumed for the design conditions within the program. The earth pressure envelopes for braced walls in sands, soft clays, and stiff clays are illustrated in Figure 3.3. For stiff clays, NAVFAC DM-7.2 (1982) recommends horizontal stresses between 0.2 and 0.4γH. The value of 0.4γH is used within the program. The stability number is calculated as \( N_s = \gamma H/c \). Where \( \gamma \) is the unit weight of the soil, \( H \) is the depth of the excavation, and \( c \) is the undrained shear strength of the soil. Characteristics of these pressure envelopes include:

a. They apply to excavations deeper than twenty feet.

b. The pressure envelopes assume the water table is below the bottom of the cut. Sands are assumed to be drained with the lowering of the ground water table behind the wall. Clays are assumed undrained and under short-term conditions.

c. Lateral stresses are apparent stresses which are to be used for the calculations of the reaction loads.
d. The behavior of an excavation in clays depends on its stability number. (Lambe and Turner, 1970)

The apparent stresses are for entire sand or clay layering only. Engineering judgment should be used for tills, silts, or fills; varying soil type with depth; and when hydrostatic stresses act on the wall.

Lambe and Turner (1970) concluded that predicting the behavior of braced excavations cannot be made with
complete confidence. This is the result of difficulty in selecting the proper soil parameters, field boundary conditions, and the details of construction. However, Ulrich (1989) concluded that the recorded pressures for overconsolidated clays agree with those developed by Peck (1969). Ulrich also noted that soil stratification does not have a significant influence on the apparent earth pressure in overconsolidated clays. In another case study in Washington D.C. where the soil stratification was layers of sands, silty sands, and stiff silty clays, the measured earth pressures fell within the apparent earth pressure envelope of 0.2γH for clays (Chapman et al., 1972). Results from other excavations in the Washington area revealed that the apparent earth pressure coefficient varied with the depth of the cut. A value of 0.15γH for a thirty foot cut, 0.2γH for a forty to fifty foot cut, and 0.23γH for a sixty foot cut (Chapman et al., 1972). The design of braced cuts is predominately based on pressure diagrams derived empirically as a result of field tests. Sound engineering judgement should be used in determining the applicability of a given pressure diagram for a particular cut.
3.2 Active and Passive Earth Pressures

For the initial two stages of construction, the soldier pile wall will develop earth pressures approaching the active and passive states. In granular soil, the soil is assumed to be drained and active earth pressures are developed as the wall deforms laterally. This is resisted by the passive resistance which is developed as the H-beam compresses the soil acting on an effective area of three times the width of the H-beam below the bottom of the excavation. However there exists some uncertainty of how the pressures act at and below the excavation line (Bowles, 1988). The active and passive earth pressure coefficients are calculated assuming Rankine's theory.

In the case of cohesive soils, undrained conditions ($\phi = 0$) are assumed with no frictional resistance developed. The stresses in the tension zone are neglected in the design computations with the depth of the tension zone taken as $z_t = (2c - q) / \gamma$ .

3.3 Hydrostatic Pressure

Hydrostatic pressure is calculated as the unit weight of water (62.4 pcf) multiplied by the height of the water table. It is assumed in the program
that sand and gravels are drained and the water table will be drawn down to the bottom of the excavation by natural seepage or mechanical dewatering. This is illustrated in Figure 3.4. Clay layering is assumed to be undrained and analyzed using either a total or effective stress analysis approach.

![Figure 3.4](image)

**Figure 3.4**
**Draw Down of Ground Water Table in Sands due to Natural Seepage or Mechanical Dewatering (NYCTA, 1974)**

3.4 Total versus Effective Stress Analysis

Some question on how to analyze the wall is raised when the ground water table is located above the bottom of the excavation in clay layering. The apparent lateral earth pressure envelopes proposed by Peck are
based on empirical data from total stress analyses. The use of a buoyant unit weight rather than the total unit weight of the soil and superimposing hydrostatic pressure onto the earth pressure diagrams change the analysis to an effective stress analysis approach. However the total stress soil parameter of undrained shear strength is still used. Therefore this effective stress analysis approach is not entirely correct.

Either a total or effective stress analysis approach may be used to design the wall. In the case of a total stress analysis, the saturated unit weight above and below the water table should be entered. For an effective stress analysis approach, the saturated unit weight above the water table and the buoyant unit weight below the water table should be used. The location of the ground water table for the effective stress analysis must therefore be located above the bottom of the cut.

Generally, the results from using the total unit weights (total stress approach) are more critical loading conditions than the approach adapted by using buoyant unit weights (Liao and Neff, 1990).
3.5 Surcharge Pressure due to a Strip Load

To account for the lateral pressures due to a strip surcharge load located at some distance from the wall face, an equivalent uniformly distributed pressure acting on the wall is developed. The total force exerted by the strip load on the wall is calculated and then converted to a uniform pressure by dividing the total force by the height of the wall. The force is calculated by the equations derived by Jarquio (1981) and as illustrated in Figure 3.5.

$$ P = 2 \frac{q \times h}{p} \times (\theta_2 - \theta_1) $$
$$ \theta_2 = \arctan \left( \frac{a + b}{h} \right) $$
$$ \theta_1 = \arctan \left( \frac{b}{h} \right) $$

**Figure 3.5**
Conversion of Strip Surcharge Load to an Uniform Pressure
3.6 NAVFAC DM-7.2 Recommendations on Flexible Wall Design

The following recommendations from Naval Facilities Engineering Command, Design Manual 7.2 (1982) were considered in the programming.

a. The total resistance force acts on an effective area of three times the flange width of the pile (3*bf) as shown in Figure 3.6. This is to account for the differences between the failure in soil of an individual pile element and that of a continuous wall for which pressure distributions were derived.

![Figure 3.6](image)

**Figure 3.6**
Effective Width of Soldier Pile that Passive Pressure Acts Upon (NYCTA, 1974)

b. For temporary construction, a factor of safety of 1.5 should be applied to passive pressures. This option is available within the program but it is not recommended. Passive resistance is calculated using Rankine's theory which is already conservative compared...
to a logarithmic spiral failure surface approach to estimate passive resistance.

c. Neglect the soil resistance to a depth of 1.5 times the pile width from the bottom of the excavation for clays and the depth of the pile width for sands. This, however, is not accomplished in the program. It was considered that significant conservativeness already exists within the wall design.

d. The required depth of embedment is calculated based on controlling the moment within the section to ensure the pile is not overstressed at the final anchor location. The active soil pressure will be resisted by the passive pressure and the allowable moment of the section.

3.7 Other Design Considerations

Other design considerations included within the program are:

a. To calculate the anchor reactions, it is assumed the piles are hinged at the bottom of the excavation and at all the anchor locations except the upper anchor. The soldier pile between each pair of hinges is assumed to be a simply-supported beam (Bowles, 1988 and Das, 1990).
b. An allowable stress for the steel soldier piles of 28,800 psi is used to calculate the required section modulus.

c. Wales are designed assuming they act as simply supported beams, pin-ended with maximum moments equal to \( w \cdot l^2 / 8 \). This moment is then increased by 33% to allow for overstressing during preload testing of the anchors. An allowable stress for the steel of 28,800 psi is used to calculate the section modulus from the maximum moment.

3.8 Design Methodology for Wall Analysis

For the first two stages of construction, the active and surcharge forces are being resisted by the passive and reaction (stage two) forces. The reaction force is calculated by summing moments about the point of net zero forces on the embedded pile assuming it is hinged there and thus zero bending moment. The maximum moment within the pile can be calculated by summing the moments about the point of zero shear. From the maximum moment, the required section modulus is calculated. The embedment depths are calculated for stage one by determining the point where the net moment is zero and for stage two by assuming fixity at the
anchor location and summing moments there so the pile is not overstressed. For clays, the stresses within the tension zone are neglected in the calculations. The force diagrams are illustrated in Figures 3.7 and 3.8 for sands and clays respectively.

Figure 3.7
Force Diagram for Stage Two of Construction in Sands

With Tension Zone:

Without Tension Zone:

Figure 3.8
Force Diagram with and without a Tension Zone for Stage Two of Construction in Clays
Kiewit design procedures are also used to calculate the maximum moments and reaction force for the initial two stages of an excavation. Kiewit procedures were developed by Peter Kiewit Sons' Company based on empirical data and field results. In the first stage, it is assumed that a pinned connection exists in the pile two feet below the bottom of the excavation. The maximum moment is calculated at this point. In the second stage, the maximum moment is taken as \( M = \frac{w \times 1}{9} \). Where \( w \) is the average pressure on the span from the first anchor to the bottom of the cut and \( 1 \) is the distance between the anchor and the bottom of the cut. The reaction force is calculated assuming pinned connections at the anchor location and the bottom of the cut.

After the second anchor is in place, the pressure distribution will correspond to those for braced cuts. Reaction forces are calculated by assuming pinned connections and summing moments about the anchor locations. Next the point of zero shear is found and moments summed about it to calculate the maximum moment. The pressure diagram for sands is depicted in Figure 3.9 and in Figures 3.10 and 3.11 for clays. Embedment depth is determined by summing moments at the
last anchor point assuming fixity so the pile is not overstressed. This is illustrated in Figure 3.12 for sands.

\[ P = \frac{3}{4} p + s = \left( \mu \tan \theta \right)^{2/2} \]

**Figure 3.9**
Pressure Diagram for Stage Three of Construction in Sands

\[ p_a = 0.4 \times s \times u \times H \]

\[ p_q = s \times q \]

\[ u = s \times u \times H_u \]

\[ p_p = \frac{6 \sqrt{s} + 2c - q}{6} \times b_l \]

**Figure 3.10**
Pressure Diagrams for Stage Three of Construction in Stiff Clays
Figure 3.11
Pressure Diagram for Stage Three of Construction in Soft to Medium Clays

Calculate \( D \) - \( \max + Pp(2/3D + H') - PA1H'/2 = 0 \)

Figure 3.12
Force Diagram for Determining the Embedment Depth in Sand Assuming Fixity about the Last Anchor Location
3.9 Tieback Anchor Capacity

In cohesionless soils, the tieback anchor capacity is calculated assuming pressure injected tiebacks using an effective grout pressure in excess of 150 psi. Figure 3.13 shows curves developed by Ostermeyer (1975) as a function of length and soil type. An average of these values was used to develop equations for each soil type to calculate anchor capacity in the program. These values assumed anchor diameters between four to six inches and a depth of overburden greater than thirteen feet.

In cohesive soils, tieback capacity is based on post-grouted anchors with grout pressures in excess of 150 psi. Figure 3.14 illustrates tieback capacity based on clay consistency. An anchor diameter of six inches was assumed to calculate tieback capacity.

3.10 Minimum Unbonded and Total Anchor Length

The unbonded length of the anchor is calculated based on locating the bonded length of the anchor outside the failure zone behind the back of the wall. The location of the failure zone is based on using the failure surfaces from Rankine's theory. Report number FHWA/RD-82/047 recommends that the length of
Figure 3.13
Load Capacity of Anchors in Cohesionless Soil
Showing the Effects of Relative Density, Gradation, Uniformity, and Anchor Length
(PHWA/RD-75/128, 1976)
Figure 3.14
Effect of Post-Grouting on Anchor Capacity in Cohesive Soils (FHWA/RD-75/128, 1976)
the anchor be of sufficient length to locate the anchor in soil which would not be affected by movement of the wall. The unbonded length should place the anchor beyond the critical failure surface as illustrated in Figure 3.15. Also recommended is a minimum unbonded length of fifteen feet to avoid load losses as a result of long term steel relaxation, creep in the soil, anchorage seating losses, and structural deformation.

![Diagram showing critical and most probable failure surfaces through the ends of tiebacks](image)

**Figure 3.15**
Determination of the Unbonded and Total Tieback Length (FHWA/RD-82/047, 1982)

The total anchor length should be of sufficient length to ensure a satisfactory factor of safety against sliding along the most critical failure surface through the ends of the anchors. If the factor
of safety is insufficient, the total anchor length should be increased (FHWA/RD-82/047, 1982). This is also illustrated in Figure 3.15.

This computer program does not calculate the factors of safety against failure of the tendons, failure in the anchor zone, or overall external stability against wall failure. Boghrat (1989) recommends the use of the STABL computer program to calculate of the total anchor length to achieve a minimum factor of safety. The user manual for PCSTABL4 is presented in the Federal Highway Administration Report No. FHWA-TS-85-229 (Carpenter and Kopperman, 1985).

3.11 Lagging Thickness

The required thickness of the wood lagging can be estimated from Table 3.1 from report number FHWA/RD-75/128 (1976). The table is based on soil type, depth of the cut, and soldier pile spacing.
<table>
<thead>
<tr>
<th>Soil Description</th>
<th>Unified Classification</th>
<th>Depth</th>
<th>Recommended Thickness (inches) of Lagging (roughcut) for Clear Sapans of:</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPETENT SOIL:</td>
<td></td>
<td></td>
<td>5'  6'  7'  8'  9'  10'</td>
</tr>
<tr>
<td>Silts to fine sand and silt above water table.</td>
<td>ML, SM-ML</td>
<td>0' to 25'</td>
<td>2  3  3  3  4  4</td>
</tr>
<tr>
<td>Sands and gravels (medium dense to dense).</td>
<td>GU, GP, GM, GC,</td>
<td>25' to 60'</td>
<td>3  3  3  4  4  4</td>
</tr>
<tr>
<td>Clays (stiff to very stiff): non-fissured.</td>
<td>CL, CH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clays, medium consistency and $\theta_{H/Su} &lt; 5$.</td>
<td>CL, CH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIFFICULT SOILS:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sands and silts, loose.</td>
<td>SW, SP, SM</td>
<td>0' to 25'</td>
<td>3  3  3  4  5  5</td>
</tr>
<tr>
<td>Clayey sands (medium dense to dense) below water table.</td>
<td>SC</td>
<td>25' to 60'</td>
<td>3  3  4  4  5  5</td>
</tr>
<tr>
<td>Clays, heavily overconsolidated: fissured.</td>
<td>CL, CH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cohesionless silt or fine sand and silt below water table.</td>
<td>ML, SM-ML</td>
<td></td>
<td></td>
</tr>
<tr>
<td>POTENTIALLY DANGEROUS SOIL:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soft clays, $\theta_{H/Su} &gt; 5$.</td>
<td>CL, CH</td>
<td>0' to 15'</td>
<td>3  3  4  5  --  --</td>
</tr>
<tr>
<td>Slightly plastic silts below water table.</td>
<td>ML</td>
<td>15' to 25'</td>
<td>3  4  5  6  --  --</td>
</tr>
<tr>
<td>Clayey plastic silts below water table.</td>
<td>SC</td>
<td>25' to 35'</td>
<td>4  5  6  --  --  --</td>
</tr>
</tbody>
</table>

Note: In the category of potentially dangerous soils, use of lagging is questionable.
4.1 Program Flow and Logic

The computer program logic and flow is illustrated in the flow charts shown in Figure 4.1. Appendix A contains the variable nomenclature for the program and the actual program file is included in Appendix B. Appendix C contains various calculations and equations used within the analysis functions in the program.

4.1.1 Main Function

The program starts with the main function which includes the main menu and exit routines. The main menu routine displays the main menu screen which prompts the user to input the next step. The options include enter soil and wall data, read data from an existing file, edit the input data, save the data in a file, execute the wall analysis, execute the anchor and wale analysis, save the analysis results, or exit the program. The program will execute the appropriate function upon input. The program will request verification before exiting.
Figure 4.1
Computer Program's Flow Chart
Figure 4.1 (Continued)
Computer Program's Flow Chart
Figure 4.1 (Continued)
Computer Program's Flow Chart
Figure 4.1 (Continued)
Computer Program's Flow Chart
Figure 4.1 (Continued)
Computer Program's Flow Chart
Figure 4.1 (Continued)
Computer Program's Flow Chart
Figure 4.1 (Continued)
Computer Program's Flow Chart

42
Figure 4.1 (Continued)
Computer Program’s Flow Chart
4.1.2 Data Functions

The data functions will input, read, edit, and save the input data or save the analysis results. The input function prompts the user for the input of the various wall and soil data. The read function prompts the user for the filename of the data. If the file does not exist in the working directory, an error message is displayed and it requests the filename be reentered or the function aborted. Upon finding the file, the data is read and entered into the appropriate program variables. The view data function displays the wall and soil data and requests if any changes are desired. If a change is desired, the number of the item and then its new value are entered. The save data function will save the input data in a DOS file in the working directory. If the file already exists, verification will be requested before coping over it. Lastly, the save function will save the results of the analysis in a DOS file. The save routine will request the filename and verification before coping over an existing file. After executing a particular routine, the program returns to the main menu.
4.1.3 Analysis Functions

The next series of functions perform the various analysis calculations. The analysis function requests entry of the estimated thickness of the pile, the factor of safety against passive pressure, and the depth of over-excavation below an anchor depth. Following input, the function determines the soil type and executes either the sand analysis or clay analysis function. After executing the sub-function and completing the calculations, flow is returned to the analysis function and the results are displayed.

The sand analysis function executes its analysis in three stages. The first stage is for the initial stage of excavation before the first anchor has been installed. It calculates the point of zero shear, maximum moment at the point of zero shear, required section modulus from the maximum moment, and the depth of embedment at the point of zero bending moment. Stage two is for the second stage of excavation after the first anchor is installed. It calculates the same items as stage one plus the reaction force. The embedment depth is based on not overstressing the pile at the anchor location assuming fixity there. Additionally for the first two stages, the moments
and reaction force are calculated using the Kiewit criteria. Stage three is executed for the stages of construction after the second and thereafter anchors are installed. The pressure distributions for braced cuts are used in this stage. The reaction forces, point of zero shear, maximum moment, and required section modulus are calculated in the function. The embedment depth is calculated by calling the sub-function, "min_D". It calculates the embedment depth from the maximum moment for each particular stage. After the final stage is completed, the minimum embedment depth is calculated from the maximum moment for all the stages of construction. The sand analysis function uses the function "ka_kp" to calculate the average unit weight, friction angles, and coefficients of passive and active earth pressures. The base friction angle and unit weight are the properties of the soil layer at the bottom of the excavation.

If the soil type is clay, the function clay analysis is executed. It performs essentially the same calculations as the sand analysis function. It first determines the location of a tension zone, if it exists, and excludes the stresses within it from any calculations. Also it verifies the soil will
support the excavation based on the net passive resistance of the structure being greater than zero ($P_{net} = 6c/ps + 2c - q > 0$). An error message is displayed if it will not. In the third stage routine, the stability number of the cut is calculated and the pressure diagram corresponding to the stability number determined. The function "ca_cb_wt" is used to calculate the average unit weight and shear strength of the cut and the base shear strength. The base shear strength is calculated from an average over a depth twenty feet below the bottom of the excavation.

Both the sand and clay analysis functions use the function "strip" to convert a strip surcharge load to an equivalent uniform surcharge load. This surcharge load is then included in the design calculations.

The anchor analysis function is used to calculates the section modulus of the wale for each row of anchors, the required anchor capacity, the bonded anchor length based on soil type and anchor capacity, and the unbonded anchor length. Prior to the actual analysis, anchor spacing; the inclination angle of the anchors; and soil type are entered. After completion of the various calculations, the results are displayed before the program returns to the main menu.
4.2 Assumptions and Limitations

1. The coefficient of passive earth pressure is calculated assuming Rankine's theory which is conservative compared to a logarithmic spiral failure surface approach in estimating the passive resistance.

2. An average unit weight and friction angle (or cohesion) for the cut is used in the soil pressure calculations. The base values for sands are the properties of the sand layer at the bottom of the excavation. For clay layering, the base value for cohesion is calculated by averaging the cohesion values over a twenty foot depth below the bottom of the excavation. This is to account for soft or stiff layers just below the bottom of the excavation. The difference between a soft and very stiff clay layer is more significant than that between a loose and dense sand. It is recommended only minimal soil layering be used.

3. A cut of entirely sand or clay layering is assumed in the program. The computer program will not accept mixed soil layering or silts. As an alternative, an equivalent value of cohesion for a sand layer may be averaged with a cohesion value of the clay layer as follows:
\[ c_v = \left[ \gamma_s K_s H_s^2 \tan \delta + (H - H_s) n' q_u \right] / 2H. \]

Where, \( H \) = total height of the cut, 
\( H_s \) = height of the sand layer, 
\( \gamma_s \) = unit weight of the sand layer, 
\( K_s \) = lateral earth pressure coefficient for the sand layer ("1), 
\( \delta \) = angle of friction of the sand layer, 
\( q_u \) = unconfined compression strength of clay, 
and 
\( n' \) = coefficient of progressive failure (ranges from 0.5 to 1). (Das, 1990)

With the average unit weight for the cut, the pressure diagrams for clays can then be used to design the wall. NYCTA (1974) recommends an alternate method where the pressure diagrams are calculated using Rankine's earth pressure theory for the individual layers and an average uniform pressure over the entire wall calculated from these pressures.

4. Sands are assumed to be drained with the water table being drawn down below to the bottom of the excavation. If the cut is not drained or the water table is not drawn down, the hydrostatic pressure should be included in the calculations.
5. For clays, short-term undrained conditions are assumed. If drainage may occur as in the cases of long-term construction (partially drained) or post-construction (fully drained), an effective stress analysis should be accomplished using effective stress parameters (\(c'\) and \(\phi'\)). Drained conditions for clays are usually more critical than undrained conditions.

6. The assumption that the wall acts as a series of pinned beams is conservative compared to assuming a continuous beam and analyzing it using a finite element approach.

7. The program does not calculate the overall stability of the structure. Most probable failure surfaces should be checked to ensure a satisfactory factor of safety.

8. The program does not check the stability of the base. Seepage forces should also be considered if present to check for quick conditions.

9. Anchor capacity is based on field testing of pressure injected tiebacks in cohesionless soils. The capacity curves used were developed with the majority of anchors less than eight meters and most were not tested to their ultimate capacity (FHWA/RD-82/047, 1982). For cohesive soils, post-grouted tiebacks are
assumed. The mechanism by which post-grouted tiebacks develop their capacity is not entirely understood. Increases in capacity of 25% to over 300% are possible depending on the soil type and the post-grouting method (FHWA-RD-82-047, 1982). The curves used represent a wide range of values and an average of these values is used to calculate capacity. The actual field capacities of the tiebacks should be verified in the field.

10. Wale design is conservatively calculated based on assuming pinned ends at the anchor locations.

4.3 Example Problems

Examples problems for sand and clay layering, with and without a ground water table present are included in Appendix D. The solutions are compared to the computer's solutions to ensure reasonable results are produced by the program.
CHAPTER FIVE
USER'S GUIDE

5.1 Program Start-Up

The program may be run either on the computer's hard drive or one of its floppy drives. From the DOS prompt, change the command prompt to the drive and directory on which the program is located. Then type SOLDIER and press enter to start the program. The program starts up and displays the main menu shown in Figure 5.1.

Figure 5.1
Main Menu Screen

Design of Soldier Pile and Lagging
In Accordance with NAVFAC DM-7

MAIN MENU

1. Enter Soil Properties and Wall Data
2. Read Data From an Existing File
3. Edit Input Data
4. Save Input Data
5. Execute Wall Analysis
6. Execute Anchor\Wale Analysis
7. Save Analysis in an Output File
8. Exit Program

Your Choice? --
The user then should enter the next step, usually enter or read data. The description of the required input data is listed in the next section. The analysis functions can only be executed after the data have been entered.

5.2 Input Data

The following data shall be entered for the various analysis functions. Figure 5.2 illustrates various input data.

Figure 5.2
Input Variables for Wall Analysis
5.2.1 Wall Data

1. Name of engineer, for maximum of 40 characters.

2. Project title, for maximum of 40 characters.

3. Date of report, for maximum of 30 characters.

4. Elevation of the top of the excavation (ft).

5. Elevation of the bottom of the excavation (ft).

6. Number of anchors used in the cut for a maximum of ten anchors.

7. Elevation of the anchors from the top of the excavation to the bottom (ft).

8. Center to center spacing of the soldier piles (ft).

5.2.2 Soil Data

1. Number of soil layers for a maximum of ten layers.

2. Soil type of the entire excavation, either one for sands or two for clays.

3. For clays, the type of the analysis to be performed (either total or effective stress analysis) is entered. If a total stress analysis is to be accomplished, the saturated unit weight of the soil
above and below the ground water table is entered. For an effective stress analysis, the saturated unit weight of the soil is entered above the water table and the buoyant unit weight entered below the water table. The elevation of the ground water table should be above the bottom of the excavation for the effective stress analysis.

4. Soil properties including elevation of the top of the layer (ft), saturated, buoyant, or moist unit weight (kcf), and friction angle (degrees) for sands or undrained shear strength (ksf) for clays.

5. Elevation of the ground water table (ft).

6. Slope of the ground surface behind the excavation (degrees).

7. Uniform surcharge load (ksf).

8. Strip surcharge load (ksf), the width of the strip load (ft), and the distance from the wall face to the start of the strip load (ft).

5.2.3 Wall Analysis Data

1. Estimated width of the flange of the soldier pile (ft).

2. Factor of safety against passive resistance.

3. Depth of over-excavation below an anchor elevation for intermediate stages (ft).
5.2.4 Anchor Analysis Data

1. The spacing of anchors (ft).

2. The angle of inclination the anchors are set from horizontal (degrees).

3. The type of soil the anchors are set in. The options include:

<table>
<thead>
<tr>
<th>Type</th>
<th>Soil Description</th>
<th>SPT N Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fine to medium sand</td>
<td>12 - 30</td>
</tr>
<tr>
<td>2</td>
<td>Medium to coarse sand</td>
<td>20 - 45</td>
</tr>
<tr>
<td>3</td>
<td>Sandy gravel</td>
<td>&gt; 45</td>
</tr>
<tr>
<td>4</td>
<td>Medium clay</td>
<td>4 - 8</td>
</tr>
<tr>
<td>5</td>
<td>Medium stiff clay</td>
<td>9 - 11</td>
</tr>
<tr>
<td>6</td>
<td>Stiff clay</td>
<td>12 - 15</td>
</tr>
<tr>
<td>7</td>
<td>Stiff to very stiff clay</td>
<td>16 - 20</td>
</tr>
<tr>
<td>8</td>
<td>Very stiff clay</td>
<td>21 - 30</td>
</tr>
<tr>
<td>9</td>
<td>Very stiff to hard clay</td>
<td>&gt; 30</td>
</tr>
</tbody>
</table>

5.3 Output Data

Figure 5.3 lists a typical output file. The output file is broken down into four sections: wall properties; soil properties; wall analysis results; and anchor and wale analysis results. The wall and soil property sections list the input data for the wall and soil under items 1 through 12.
I. WALL PROPERTIES

1. Engineer: D'Amanda
2. Project: International Corporate Park
3. Date: 10 November 1989
4. The elevation of the top of the excavation is 102.00 feet.
5. The elevation of the bottom of the excavation is 81.00 feet.
6. The number of anchors is 2.
   The anchors are located as follows:
   Anchor   Elevation (feet)
   1        96.00
   2        89.00
7. The spacing of the soldier piles is 5.00 feet.

II. SOIL PROPERTIES

8. The elevation of the water table is 50.00 feet.
9. The soil properties are as follows:

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Elev</th>
<th>Unit Wt</th>
<th>Friction Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>sand</td>
<td>102</td>
<td>0.1150</td>
<td>38.00</td>
</tr>
</tbody>
</table>

10. The slope of the ground behind the wall is 31.5 degrees.
11. The surcharge load is 0.250 ksf.
12. The strip load is 0.50 ksf, 10.00 feet wide, and located 45.0 feet from the wall.

III. WALL ANALYSIS RESULTS

13. Estimated width of the soldier pile is 0.5 feet.
14. Factor of safety for passive resistance is 1.0.
15. The wall was excavated 1.0 feet below the proposed anchor location.

Figure 5.3
Sample Output File
### 16. Stage Zero Maximum Section Embedment

<table>
<thead>
<tr>
<th>Reaction(s)</th>
<th>Shear Moment (ft)</th>
<th>Modulus (k-ft)</th>
<th>Modulus (in^3)</th>
<th>Depth (ft)</th>
<th>(kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.1</td>
<td>55.23</td>
<td>23.01</td>
<td>10.1</td>
<td>---</td>
</tr>
<tr>
<td>2</td>
<td>21.9</td>
<td>20.45</td>
<td>8.52</td>
<td>5.5</td>
<td>R1 = 19.10</td>
</tr>
<tr>
<td>3</td>
<td>17.0</td>
<td>27.86</td>
<td>11.61</td>
<td>4.6</td>
<td>R1 = 42.04</td>
</tr>
</tbody>
</table>

**NOTE:**
- Stage 1 moment based on Kiewit criteria is 42.1 kip-ft.
- Stage 2 moment based on Kiewit criteria is 19.0 kip-ft and reaction force is 16.7 kips.

**NOTE:** Minimum depth of embedment based on maximum moment is 3.8 feet.

**NOTE:** NYCTA recommends minimum penetration depth of six feet.

### IV. Anchor and Wale Results

17. Spacing of the anchors is 10.0 feet.
18. The anchors are set at an angle of 5.0 degrees.
19. The anchors are set in medium to coarse sand.
20. Anchors

<table>
<thead>
<tr>
<th>Anchor Section</th>
<th>Modulus (in^3)</th>
<th>Anchor Capacity (kips)</th>
<th>Anchor Length (ft)</th>
<th>Unbonded Length (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>58.4</td>
<td>84</td>
<td>7.4</td>
<td>7.0</td>
</tr>
<tr>
<td>2</td>
<td>23.8</td>
<td>34</td>
<td>4.0</td>
<td>3.8</td>
</tr>
</tbody>
</table>

**NOTE:** Tieback capacity is based on pressure injected anchors using and effective grout pressure in excess of 150 psi with a diameter between 4 to 6 inches and depth of overburden greater than 13 feet.

**NOTE:** FHWA/RD-82/047 recommends a minimum unbonded length of 15 feet.

**End of Analysis**
In the wall analysis results section, items 13 through 15 are the input values for the width of the pile, factor of safety for passive resistance, and the depth of over-excavation respectively. The actual results from the analysis are listed under item 16 and include: stage; point of zero shear; maximum moment; embedment depth; and reaction forces. The location of the point of zero shear is from the top of the pile. The depth of embedment is calculated from the maximum moment for that particular stage and is measured from the bottom of the cut. Four notes may be displayed within this section. The results using the Kiewit criteria for the first two stages are listed in the first note. The next note lists the minimum depth of embedment based on the maximum moment from all stages of excavation. If the penetration depth for the last stage or the minimum embedment depth is less than six feet, a note is displayed indicating NYCTA (1974) recommends a minimum penetration depth of six feet. The last note is displayed for clay layering stating the type of analysis, either total or effective stress, used in the calculations.

The anchor and wale analysis results section lists the anchor spacing, inclination angle of the
anchor, and soil type under items 17 through 19. The results of the analysis are listed under item 20. It includes anchor row, section modulus of the wale, required anchor capacity, (bonded) anchor length, and unbonded anchor length. A note is displayed stating how the anchor capacity was derived. Another note is displayed if the unbonded length of the anchor is less than fifteen feet. FHWA/RD-82/047 recommends a minimum unbonded length of fifteen feet.

5.4 Error Messages

The follow error messages are possible within the program:

"You must input or read data before editing them." Data must be entered or read before selecting the edit function.

"You must input or read data before you save them." Data must be entered or read before selecting the save data function.

"You must input or read data before analysis." Data must be entered or read before selecting the wall analysis function.

"You must accomplish wall analysis before you can save it." The wall analysis function must be accomplished before selecting the save function.
"You must accomplish wall analysis before this analysis." The wall analysis function must be accomplished before selecting the anchor/wale analysis function.

"The bottom of the excavation must be below the top." The elevation entered for the bottom of the excavation must be below the top of the excavation.

"The elevation of this anchor must be below the prior anchor or the top of the excavation and above the bottom of the excavation." The elevation entered for the anchor location must be below the previous anchor location or the top of the excavation and above the elevation of the bottom of the excavation.

"The location of the water table can not be above the top of the excavation." The elevation of the ground water table must be entered below the elevation of the top of the excavation.

"The soil type must be either 1 (sands) or 2 (clays)." The soil type for the cut must be entered either 1 or 2 for sands and clays respectively.

"The first layer must extend to the top of the excavation." For the first soil layer, the elevation of the top of the layer must extend to the top of the excavation.
"The elevation of the top of the soil layer must be below the last layer." The elevation entered for the top of a soil layer must be below the elevation of the previous layer.

"The location of the ground water table must be above the bottom of the excavation for an effective stress analysis." When using an effective analysis approach to calculate stresses for clay layering, the ground water table must be located above the bottom of the excavation. The buoyant unit weight of the soil should be entered below the water table.

"Trouble opening 'filename' -- Read mode. Reenter the filename or type abort to return to the main menu." The filename entered for read data does not exist in the working directory. Either the filename must be reentered or abort entered to return to the main menu.

"Width must be positive." The estimated width of the flange of the soldier pile must be entered as a positive number.

"Factor of safety must be positive." The factor of safety for passive resistance must be entered as a positive number.

"Soil will not support the wall below a depth of XX.X feet." For clay layering, the soil will not support the wall below the depth listed.
CHAPTER SIX
CONCLUSIONS

6.1 Review of Objectives

The objective of the computer program was to provide a rapid and effective method to analyze braced excavations. By varying the number and location of tieback anchors, the design of a soldier pile and lagging wall may be optimized. Once an initial design is computed, the engineer may then accomplish final design calculations based on the results from the computer program. This will significantly reduce the time to accomplish an actual design.

6.2 Summary of Design Procedures

Recommended design procedures are first to determine the soil conditions, wall requirements, and any surcharge loads. Next, select an initial number of anchors and their respective locations. Then run the program with the selected data, revising the number and locations of the anchors until the reaction forces and required section modulus are within acceptable limits. A soldier pile section may be
selected from the Manual of Steel Construction (1980) based on the required section modulus. Lagging size may be chosen from the design table included in chapter three (Table 3.1) from FHWA/RD-75/124 (1976). The anchor analysis function of the program may be used to estimate the wales' section modulus and the unbonded and bonded length of the tieback anchors. Spacing of the anchors may be varied until acceptable results are produced. Also by adjusting the input parameters, the effects of a ground water table; different soil conditions; or increased surcharge loading may be analyzed.

The program does not check the overall stability of a wall and the surrounding soil mass. The soil pressure acting against a wall may be greater in the case of slope stability than for braced cuts and thus govern wall design. Also, the factors of safety against failure of the steel tendons of the anchors and failure in the anchor zone should be verified separately. The computer program PCSTABL can be used to accomplished this analysis.
6.3 Conclusions

The program SOLDIER.EXE can provide the engineer with a quick and effective method of designing a soldier pile and lagging wall. With the program, the engineer can also investigate the effects of differing soil conditions, water table location, surcharge loading, and wall dimensions and properties.

The engineer must understand the design concepts and assumptions made within the program to ensure they are applicable to a particular project. This computer program is not intended to be a replacement for a complete design by a competent engineer. The stresses produced by braced cuts can only be roughly estimated and a monitoring system should be employed for critical cuts to ensure the acceptable performance of the wall. The overall satisfactory performance of the wall depends greatly on determining accurate soil parameters, the external loading conditions, and the use of proper construction procedures.
APPENDIX A

VARIABLE NOMENCLATURE
The nomenclature of the variables used within the program are listed as follow.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition (units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>engineer</td>
<td>Name of engineer, for maximum of 40 characters.</td>
</tr>
<tr>
<td>project</td>
<td>Project title, for maximum of 40 characters.</td>
</tr>
<tr>
<td>date</td>
<td>Date of report, for maximum of 30 characters.</td>
</tr>
<tr>
<td>telev</td>
<td>Top elevation of the excavation (ft).</td>
</tr>
<tr>
<td>bellev</td>
<td>Bottom elevation of the excavation (ft).</td>
</tr>
<tr>
<td>numa</td>
<td>number of anchors used in the cut excavation.</td>
</tr>
<tr>
<td>s</td>
<td>Spacing of the soldier piles (ft).</td>
</tr>
<tr>
<td>gwt</td>
<td>Elevation of the water table (ft).</td>
</tr>
<tr>
<td>nums</td>
<td>Number of soil layers.</td>
</tr>
<tr>
<td>soil_type</td>
<td>Type of soil. Either one for sands or two for clays.</td>
</tr>
<tr>
<td>soil[10][3]</td>
<td>Soil properties for maximum of ten layers: Elevation of top of the layer (ft), saturated or moist unit weight (kcf), and friction angle (degrees) or cohesion value (ksf).</td>
</tr>
<tr>
<td>b</td>
<td>Slope of the ground behind the excavation (degrees).</td>
</tr>
<tr>
<td>q</td>
<td>Surcharge load (ksf).</td>
</tr>
<tr>
<td>bf</td>
<td>Estimated thickness of flange of soldier pile (ft).</td>
</tr>
</tbody>
</table>
\textbf{fs} Factor of safety against passive resistance.

\textbf{w} Depth of over-excavation below the anchor elevation for intermediate stages (ft).

\textbf{d} Spacing of anchors (ft).

\textbf{ang} Inclination angle the anchors are set (degrees).

\textbf{type} Soil type for anchor analysis calculations.

\textbf{pi} Constant value of 3.141592654.

\textbf{filename} Name of file to save or read data or to save analysis, for maximum of 10 characters.

\textbf{wt} Average saturated or moist unit weight of cut soil (kcf).

\textbf{fa} Average Friction angle of soil (degrees).

\textbf{wtb} Saturated or moist unit weight of base soil (ksf).

\textbf{fab} Friction angle of base soil (degrees).

\textbf{Ka} Coefficient of active earth pressure for the cut soil.

\textbf{Kab} Coefficient of active earth pressure for the base soil.

\textbf{Kp} Coefficient of passive earth pressure for the base soil.

\textbf{sigh} Horizontal stress or force due to soil (ksf or kips).

\textbf{sigs} Horizontal stress or force due to surcharge (ksf or kips).
<table>
<thead>
<tr>
<th>PP</th>
<th>Net passive resistance pressure or force (ksf or kips).</th>
</tr>
</thead>
<tbody>
<tr>
<td>u</td>
<td>Hydrostatic force or stress (kips or ksf).</td>
</tr>
<tr>
<td>ca</td>
<td>Undrained shear strength of cut clay soil (ksf).</td>
</tr>
<tr>
<td>cb</td>
<td>Average undrained shear strength of base clay soil (ksf).</td>
</tr>
<tr>
<td>Ns</td>
<td>Stability number of the cut for clays.</td>
</tr>
<tr>
<td>zt</td>
<td>Length of tension zone for clays (ft).</td>
</tr>
<tr>
<td>R[10][10]</td>
<td>Reaction forces for each stage of construction (kips).</td>
</tr>
<tr>
<td>Mmax</td>
<td>Maximum moment from all stages of excavation (kip-ft).</td>
</tr>
<tr>
<td>Dmin</td>
<td>Minimum embedment depth calculated using Mmax (ft).</td>
</tr>
<tr>
<td>Mk[2]</td>
<td>Maximum moment from Kiewit Analysis for stage one and two of sand analysis (kip-ft).</td>
</tr>
<tr>
<td>Rk</td>
<td>Reaction force from Kiewit Analysis for stage two of sand analysis (kips).</td>
</tr>
</tbody>
</table>
sw[10]  Section Modulus of wale (in^3)
bp       Used as a flag.
c        Dummy character.
cc[20]   Dummy characters, for maximum of twenty.
H, h, hh, hhh Various height of the cut variables (ft).
a, v, y   Internal variables used in various calculations.
i, j, k, l Global counters.
ij, jk    Local counters.
str_anal  Type of stress analysis to be performed for clay layering. Either 1 for total or 2 for effective stress analysis.
APPENDIX B

COMPUTER PROGRAM FILE
// *****************************/
// * SOLDIER.EXE, Version 1.01, dtd 15 NOV 91
// * Program written by Kevin D'Amanda.
// * Address until Jan 95:
// * COMCBLANT, Naval Amphibious Base Little Creek,
// * Norfolk, VA 23521-5070
// *****************************/

#include <conio.h>
#include <stdio.h>
#include <ctype.h>
#include <stdlib.h>
#include <complex.h>
#include <string.h>

// *****************************/
// * DECLARE FUNCTION
// *****************************/

void input(void);
void read_data(void);
void save_data(void);
void view_data(void);
void analysis(void);
void anchor(void);
void ka_kp(void);
void clay_analysis(void);
void wt_ccb(void);
void sand_analysis(void);
void save(void);
void min_D(void);
void strip(void);

// *****************************/
// * DECLARE VARIABLES
// *****************************/

float belev = 0, telev = 0, s = 0, gwt = 0, q = 0, b = 0,
anc[10], soil[10][3], hh = 0, H, sw[10], d = 0, ang = 0, L[10],
ul[10], bf = 0, fs = 0, w = 0, qs[3];
double sigh, sigs, wt, fa, v, y, Ka, Kp, Kab, wtb, fab, u, P[10],
Mc[2], Rc, qe, Mmax, Dmin, z[11], D[11], M[11], S[11],
R[10][10], zt, pp, cb, ca, Mk[2], Rk;
int type = 0, numa = 0, nums = 0, i = 0, k = 0, j = 0, l = 0,
bp = 0, soil_type, str_anal;
const float pi = 3.141502654;
char c = 'x', cc[20], filename[10], engineer[40], project[40],
date[30];
main(void) {

for (i =0; i < 10; i++)
    { for (k = 0; k < 3; k++) soil[i][k] = 0;
     for (j = 0; j < 10; j++) R[i][j++] = 0;
         L[i] = 0; }

clrscr();
cout << "\n"
<< "
" << "
" << "
" << "

Design of Soldier Pile and Lagging
In Accordance with NAVFAC DM-7

while ((i = atoi(gets(cc))) <=0 || i >9) { cout << "\n\tYour Choice? -- ";
case 1: input(); bp = 1; break;
case 2: read_data(); bp = 1; break;
case 3: if (bp) view_data();
else ( clrscr();
cout << "\n\n\tERROR - You must input or read data before you edit them!" << "\n\tPress the enter key to return to the
main menu. \a"
gets(cc); } 
break;
case 4: if (bp) save_data(); 
else { clrscr(); 
cout << "\n\n\n\nERROR - You must input or read data before you 
save them!" << "\n\t Press the enter key to return to 
the main menu.\a";
gets(cc); } 
break;
case 5: if (bp) { analysis(); bp = 2;} 
else { clrscr(); 
cout << "\n\n\n\nERROR - You must input or read data before 
analysis!" << "\n\t Press the enter key to return to the 
main menu.\a";
gets(cc); } 
break;
case 6: if ((bp > 1) && (numa > 0)) anchor(); 
if (numa == 0) { clrscr(); 
cout << "\n\n\n\n There are no anchors in the wall data, 
therefore" << "\n\t anchor analysis is not required." << "\n\n\t Press the enter key to return to the main menu.\a";
gets(cc); } 
if (bp <= 1) { clrscr(); 
cout << "\n\n\n\nERROR - You must accomplish wall analysis before 
this analysis!" << "\n\t Press the enter key to return 
to the main menu.\a";
gets(cc); } 
break;
case 7: if (bp > 1) save(); 
else { clrscr(); 
cout << "\n\n\n\nERROR - You must accomplish wall analysis before 
you can save the data!" << "\n\t Press the enter to 
return to the main menu.\a";
gets(cc); } 
break;

// ****************************************************************************** 
// * 
// ******************************************************************************
case 8: cout << "\n\t Are you sure you want to quit the program? 
(Y/N) -- "; 
do { gets(cc); 
c = toupper(cc[0]); 
if (((c == 'Y') || (c == 'N'))) break; 
cout << "\n\t That's not Yes or No, please enter a Y or N. -- \a"; 
} while (((c != 'Y') || (c != 'N'))); 
if (c == 'Y') {

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void input(void) {
clrscr();
cout << "\n\n\tWall Properties\n";
cout << "\n\tEnter the Engineer's name. -- ";
gets(engineer);
cout << "\n\tEnter the project name. -- ";
gets(project);
cout << "\n\tEnter the date. -- ";
gets(date);
cout << "\n\tEnter the elevation of the top of the excavation in feet. -- ";
cin >> telev;
cout << "\n\tEnter the final elevation of the bottom of the excavation. -- ";
cin >> belev;
if (belev >= telev)
{ cout << "\nERROR - The bottom of the excavation must be below the top!\n" << "\n\tReenter the final elevation of the excavation. -- a\n";
cin >> belev; }
cout << "\n\tEnter the number of anchors that are to be used to support the excavation for a maximum of ten anchors. -- ";
cin >> numa;
if (numa) {
cout << "\n\tEnter from the top to bottom the elevation in feet of the anchor(s).\n";
hh = telev;
j = 0;
for (i = 0; i < numa; ++i) {
cin >> anc[j];
while (anc[j] >= hh && anc[j] <= belev)
{ cout << "\n\tERROR - The elevation of this anchor must be below the prior anchor or\n\tthe top of the excavation and above the bottom of the excavation.\n\tReenter the elevation of this anchor. -- a\n";
cin >> anc[j]; }
hh = anc[j]; ++j; }
cout << "\n\tEnter the spacing of the soldier piles. -- ";
cin >> s;
cnscr();
cout << "\n\t\t\tSoil Properties\n\n";
cout << "\n\tEnter the number of soil layers for a maximum of ten
layers. -- ";
cin >> nums;
cout << "\n\tEnter the soil type, either 1 for sands or 2 for
clays. -- ";
cin >> soil_type;
while ((soil_type <= 0) )); (soil_type >= 3)) {};
cout << "\n\n\tERROR - The soil type must be either 1 (sands) or
2 (clays). a" << "\n\tPlease reenter soil type. -- ";
cin >> soil_type;
cnscr();
if (soil_type == 1) {
cout << "\n\n\tEnter the soil layering properties as follows from
top down:\n" << "\n\tElevation of the top of the soil layer in
feet from top down." << "\n\tMoist or saturated unit weight of
the soil (kips/ft^3)." << "\n\tFriction angle (degrees)." << "\n\t(The entry should read like: 100 .115 35)" << "\n\n\tNOTE: The top of the excavation is at elevation " <<
telev << " feet.\n"; }
else {
cout << "\n\n\tDo you wish to perform a total or effective stress
analysis?";
cout << "\n\n\tIf you would like to accomplish a TOTAL STRESS
ANALYSIS enter" << "\n\tthe saturated unit weight of the soil
above and below the" << "\n\tground water table.";
cout << "\n\n\tIf you would like to accomplish an EFFECTIVE
STRESS ANALYSIS" << "\n\tenter the saturated unit weight of
the soil above the water" << "\n\ttable and the buoyant unit weight
of the soil below the water" << "\n\n\ttable. The water table
elevation should be located above the" << "\n\n\tbottom of the
cut.";
cout << "\n\n\tEnter 1 for a total stress analysis and 2 for an
effective" << "\n\tstress analysis. -- ";
cin >> str anal;
while ((str anal <= 0) )); (str anal >= 3)) {};
cout << "\n\n\n\tERROR - Please enter either a 1 (total) or 2
(effective). --a";
cin >> str anal; }
cnscr();
cout << "\n\tEnter the soil layering properties as follows from
top down:" << "\n\tElevation of the top of the soil layer in
feet from top down." << "\n\tSaturated or buoyant unit weight of
the soil (kips/ft^3)." << "\n\tUndrained shear strength (ksf)." << "\n\t(The entry should read like: 100 .115 1.5)" << "\n\n\tNOTE: The top of the excavation is at elevation " <<
telev << " feet.\n"; }

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hh = 1E10;  j = 0;
for (i = 0; i < nums; ++i) {
  cin >> soil[j][0] >> soil[j][1] >> soil[j][2];
  while ((soil[j][0] > hh) || (soil[0][0] != telev))
    if (soil[j][0] > hh)
      cout << "\nERROR - " << "\n The elevation of the top of the
    soil layer must be below the last layer." << "\n Reenter
    all the soil data for this layer. -- \a";
    if (soil[0][0] != telev)
      cout << "\nERROR - The first layer must extend to the top of the
    excavation" << "\n Reenter all the soil data for this
    layer. -- \a";
  cin >> soil[j][0] >> soil[j][1] >> soil[j][2]; }
hh = soil[j][0];  ++j;
clrscr();
cout << "\n\tEnter the elevation of the water table in feet. -- ";
 cin >> gwt;
while (gwt > telev) {
  cout << "\n\nERROR - " << "\n The location of the water table can
    not be above the top of the excavation." << "\n Reenter the
    location of the water table. -- \a";
  cin >> gwt; }
while ((str_anal == 2) && (gwt < belev)) {
  cout << "\n\nERROR - The location of the ground water table must
    be above the bottom" << "\n of the excavation for an
    effective stress analysis." << "\n Reenter the location
    of the water table. -- \a";
  cin >> gwt; }
cout << "\n\tEnter the slope of the ground behind the wall in
    degrees. -- ";
 cin >> b;
cout << "\n\tEnter the surcharge load (ksf)." << "\n\tPlease
    enter 0 if none. -- ";
 cin >> q;
cout << "\n\tEnter the data for any strip load:" << "\n\tSurcharge load (ksf), width of strip load (ft)," << "\n\tand
    the distance the strip load is from the wall (ft)."; cout << "\n\n\tPlease enter 0's if none. -- ";
cin >> qs[0] >> qs[1] >> qs[2];
clrscr(); }

// ********************************************************************
// READ DATA FUNCTION
// * Read data from a existing DOS file to enter variables.
// ********************************************************************
void read_data(void) {
    char *cx = "ABORT";
    clrscr();
    cout << "\n\nEnter filename. -- ";
    gets(filename);
    FILE *ffp;
    while ((ffp=fopen(filename, "r")) == NULL) {
        printf("\nERROR - Trouble opening %s -- read mode.\a", filename);
        cout << "\n\nReenter the filename or type ABORT to return to the
main menu. -- ";
        gets(filename);
    }
    FILE *ftp;
    gets(ftp);
    j = strlen(filename);
    for (i = 0; i < j; i++) filename[i] = toupper(filename[i]);
    if (strcmp(filename, cx) == 0) break;
    if (strcmp(filename, cx) != 0) {
        fgets(engineer, 60, ftp);
        fgets(project, 60, ftp);
        fgets(date, 30, ftp);
        fscanf(ffp, "\n%f\n%f\n%f\n%d\n", &telev, &belev, &s, &numa);
        for (i = 0; i < numa; ++i)
            fscanf(ffp, "\n%f\n", &anc[i]);
        fscanf(ffp, "\n%f\n%d\n%d\n%d", &gwt, &nums, &soil_type, &str_anal);
        for (i = 0; i < nums; ++i)
            fscanf(ffp, "\n%f\n%f\n%f", &soil[i][0], &soil[i][1], &soil[i][2]);
        fscanf(ffp, "\n%f\n%f\n%f\n%f\n%f", &b, &q, &qs[0], &qs[1], &qs[2]);
        fclose(ffp);
        cout << "\n\Please reenter: Engineer's name. -- ";
        gets(engineer);
        cout << "\tProject title. -- ";
        gets(project);
        cout << "\tDate. -- ";
        gets(date);
        cout << "\n\Data read, press enter key to continue.";
        gets(cc); }
}

// ************************************************************************
// *                                                                         
// * VIEW AND EDIT ENTERED DATA FUNCTION                                     
// * View and edit entered program variables.                              
// ************************************************************************

void view_data(void) {
    WALL: clrscr();
    cout << "\n\tALL PROPERTIES\n";
    printf("\n	Engineer: %s", engineer);
}
printf ("\n\t2. Project: \%s", project);
printf ("\n\t3. Date: \%s", date);
cout << "\n\t4. The elevation of the top of the excavation is " << telev << " feet." << "\n\t5. The elevation of the bottom of the excavation is " << belev << " feet." << "\n\t6. The number of anchors is " << numa << ".";
if (numa)
cout << "\n\tThe anchors are located as follows:\n" << "\tAnchors << "\tElevation (feet)\n";
j = 0;
for (i = 0; i < numa; ++i)
{ printf("\t\t%2d %5.2f\n", ++j, anc[i]); }
cout << "\n\t7. The spacing of the soldier piles is " << s << " feet.";
cout << "\n\tDo you want to change any values? (Y/N) -- ";
do { gets(cc);
c = toupper(cc[0]);
if (((c == 'Y') || (c == 'N')) break;
else {
cout << "\n\t" << cc << " is an incorrect response, try again -- \a"; }
} while (c != 'N');
if (c == 'N') { SOIL: clrscr();
cout << "\n\tS O I L P R O P E R T I E S";
cout << "\n\t8. The elevation of the water table is " << gwt << " feet." << "\n\t9. The soil properties are as follow:\n" << "\n\t Soil Type Elev Unit Wt Friction Angle" << "\n\t or Cohesion";
j = 0;
for (i = 0; i < nums; ++i) {
cout << "\n\t";
if (soil_type == 1) cout << "sand";
else cout << "clay";
printf("\n\t %7.2f %1.4f %5.2f", soil[j][0], soil[j][1], soil[j][2]);
j++;
} cout << "\n\t10. The slope of the ground behind the wall is " << b << " degrees.";
cout << "\n\t11. The surcharge load is " << q << " ksf.";
printf ("\n\t12. The strip load is %7.2f ksf, %4.2f feet wide,", qs[0], qs[1]);
printf("\n\t and located %5.1f feet from the wall.", qs[2]);
cout << "\n\tDo you want to change any values? (Y/N) -- ");
do { gets(cc);
c = toupper(cc[0]);
if (((c == 'N') || (c == 'Y')) break;
else {
cout << "\n\t" << cc << " is an incorrect response, try again -- \a"; }
} while (c != 'Y');
79
if (c == 'Y') {
  cout << "Enter the number of what you want to change -- ";
  while ((i = atoi(gets(cc))) <= 0 || i >= 13)
    { cout << "is an incorrect response.\a";
     cout << "Your choice? --"; }
  clrscr();
  switch (i) {
    case 1: cout << "Enter the Engineer's name -- ";
           gets(engineer);
           break;
    case 2: cout << "Enter the project name. -- ";
           gets(project);
           break;
    case 3: cout << "Enter the date. -- ";
           gets(date);
           break;
    case 4: cout << "Enter the elevation of the top of the
           excavation in feet. -- ";
           cin >> telev;
           soil[0][0] = telev;
           break;
    case 5: cout << "Enter the elevation of the bottom of the
           excavation in feet. -- ";
           cin >> belev;
           break;
    case 6:
      cout << "Enter the number of anchors that are to be used. -- ";
      cin >> numa;
      hh = 0;
      if (numa != 0)
        { j = 0;
         cout << "Enter from the top to bottom the elevation in feet
            of the anchor(s) --\n"
         for (l = 0; l < numa; ++l)
           { cin >> anc[j];
             hh = telev;
             while (anc[j] >= hh || anc[j] <= belev) {
               cout << "ERROR- The elevation of this anchor must be below
                the top of the excavation
                and above the bottom of the excavation." << "Enter the
                elevation of this anchor. -- \a"
               cin >> anc[j]; }
             hh = anc[j]; ++j; } }
break;
case 7:
cout << "Enter the spacing of the soldier piles. -- ";
cin >> s;
cin = cin >> wgt;
break;
case 8: cout << "Enter the elevation to the water table in feet. -- ";
cin >> gwt;
if (gwt > telev) {
cout << "ERROR - " << " The location of the water table can not be above the top of the excavation." << " Reenter the location of the water table -- 
"
cin >> gwt; }
break;
case 9: cout << "Enter the number of soil layers. -- ";
cin >> nums;
cout << "Enter the soil type, either 1 for sands or 2 for clays. -- ";
cin >> soil_type;
while ((soil_type <= 0) || (soil_type >= 3)) {
cout << "ERROR - The soil type must be either 1 (sands) or 2 (clays)." << " Please reenter soil type. -- 
";
cin >> soil_type; }
if (soil_type == 2) {
cout << "Do you wish to perform a total or effective stress analysis?" << " Enter 1 for a total stress analysis and 2 for an effective " << "stress analysis. -- ";
cin >> str_anal;
while ((str_anal <= 0) || (str_anal >= 3)) {
cout << "ERROR - Please enter either a 1 (total) or 2 (effective). -- 
";
cin >> str_anal; }
cout << "Enter the soil layer's properties:" << " Enter the elevation of top of the layer, unit weight, and friction angle" << " or undrained shear strength. 
"
hh = 1E8; j = 0;
for (i = 0; i < nums; ++i) {
cin >> soil[i][0] >> soil[i][1] >> soil[i][2];
while ((soil[i][0] > hh) || (soil[i][0] != telev))
{ if (soil[i][0] > hh)
cout << "ERROR - " << " The elevation of the top of the soil layer must be below the last layer." << " Reenter all the soil data for this layer. -- 
";
if (soil[i][0] != telev)
cout << "ERROR - The first layer must extend to the top of the excavation" << " Reenter all the soil data for this layer. -- 
";
cin >> soil[i][0] >> soil[i][1] >> soil[i][2]; }
hh = soil[i][0]; ++j; }
break;
case 10: cout << "\n\tEnter the slope of the ground behind the
   wall in degrees. -- ";
cin >> b;
break;
case 11: cout << "\n\tEnter the surcharge load (psf)." <<
      "\n\tPlease enter 0 if none. -- ";
cin >> q;
break;
case 12:
   cout << "\n\tEnter the data for any strip load:" << "\n\tSurcharge load (ksf), length of strip load (ft)," << "\n\tand the distance the strip load is from the wall (ft).";
   cout << "\n\tPlease enter 0 if none. -- ";
cin >> qs[0] >> qs[1] >> qs[2];
   break; }
c1rscr();
if (i < 8) goto WALL;
   else goto SOIL; } }

// *************** SAVE DATA FUNCTION
// * Save entered data into a DOS file.
// ***************

void save_data(void) {
   FILE *fp;
c1rscr();
cout << "\n\tEnter filename to save the data. -- ";
gets(filename);
while ((fp=fopen(filename, "r")== NULL) {
   cout << "\n\tThe file already exits, do you want to overwrite it?
   (Y/N) -- \a";
gets(cc);
c = toupper(cc[0]);
switch (c) {
   case 'Y': break;
   case 'N': cout << "\n\tReenter the filename. -- ";
   gets(filename);
   break;
   default :
   cout << "\n\t" << cc << " is an incorrect response, try again. -- \a";
   gets(cc);
c = toupper(cc[0]); } }
if (c == 'Y') { c = 'X'; break; } }
fp = fopen(filename, "w+");
fprintf(fp, "%s", engineer);
fprintf(fp, "%s", project);}
fprintf(fp, \"\n %s\", date);
fprintf(fp, \"\n %f\", telev);
fprintf(fp, \"\n %f\", belev);
fprintf(fp, \"\n %f\", s);
fprintf(fp, \"\n %d\", numa);
for (j = 0; j < numa; ++j) fprintf(fp, \"\n %f\", anc[j]);
fprintf(fp, \"\n %f\", gwt);
fprintf(fp, \"\n %d\", nums);
fprintf(fp, \"\n %d\", soil_type);
fprintf(fp, \"\n %d\", str_anal);
for (i = 0; i < nums; ++i)
fprintf(fp, \"\n %f %f %f\", soil[i][0], soil[i][1], soil[i][2]);
fprintf(fp, \"\n %f\", b);
fprintf(fp, \"\n %f\", q);
fprintf(fp, \"\n %f %f %f\", qs[0], qs[1], qs[2]);
cprintf(fp);
close(fp);
cout << \"\n\tData saved, press enter key to return the main menu.\";
gets(cc);
clsr();

void analysis(void) {

clsr();
// Enter Width of Pile, Factor of Safety, & Excav. Depth

cout << \"\n\tEnter the estimated width of the flange of the soldier pile.\" << \"\n\t(Enter 0 for default setting of 1 foot.) -- \";
cin >> bf;
if (bf < 0) {
cout << \"\n\tERROR - Width must be positive, Reenter width -- \";
cin >> bf;}
if (bf == 0) bf = 1;
cout << \"\n\tEnter the factor of safety for the passive pressure.\" << \"\n\t(Enter 0 for DM-7 recommendation of 1.5.) -- \";
cin >> fs;
if (fs < 0) {
cout << \"\n\tERROR - Factor of safety must be positive, Reenter F.S. -- \";
cin >> fs;}
if (fs == 0) fs = 1.5;
if (numa) {
cout << "Enter the depth in feet below the anchor location that is to " << "exavated prior to installing the anchor. -- " ;
cin >> w; }
c1rsc.
cout <<"CALCULATING; if (soil_type == 1) sand_analysis();
if (soil_type == 2) clay_analysis();
if (z[0] >= 0) { i = 1, j = 0;
c1rscr();
cout <<"RESULTS:" << "Estimated width of the soldier pile is " << w << " feet."
cout <<"The wall was excavated " << w << " feet below the proposed anchor location."
cout <<"STAGE ZERO MAXIMUM SECTION EMBEDMENT REACTION(S)" << "(ft) (k-ft) (in^3)
Wt (ft) (kips)" << "------------------
------------------------------
"
printf("%d %6.1f %6.2f %6.2f %6.1f
---", i, z[i-1], M[i-1], S[i-1], D[i-1]);
for (i = 2; i <= numa + 1; ++i) {
printf("%d %6.1f %6.2f %6.2f %6.1f
", i, z[i-1], M[i-1], S[i-1], D[i-1], R[0][i]);
for (k = 2; k <= numa; ++k) {
if (R[k-1][j]) {
cout << "R" << k << " = ";
printf("%6.2f", R[k-1][j]); } } ++j; }
printf("NOTE: Stage 1 moment based on Kiewit criteria is %6.1f kip-ft.", Mk[0]);
if (numa > 0) {
printf("Stage 2 moment based on Kiewit criteria is %6.1f kip-ft.", Mk[1]);
printf("and reaction force is %6.1f kips.", Rk); }
if (numa > 1) printf("Minimum depth of embedment based on maximum moment is %3.1f feet.", Dmin);
if ((D[numa] < 6) || (Dmin < 6)) {
cout << "NOTE: NYCTA recommends minimum penetration depth of six feet.;
}
if ((soil_type == 2) & (str_anal == 1))
printf("A total stress analysis approach was used.");
if ((soil_type == 2) & (str_anal == 2))
printf("An effective stress analysis approach was used.");
cout << "Press the enter key to return to the main menu. ";
gets(cc); }
void sand_analysis(void)
{
    j = 0; i = 0; v = 0; y = 0;
    if (numa) hh = anc[j] - w;
    else hh = belev;
    ka_kp();
    strip();
    hh = telev - hh;
    sigh = Ka*wt*hh*s*hh/2; // Horizontal Stress due to Soil
    sigs = Ka*qe*s*hh; // Horizontal Stress due to Surcharge
    pp = (3*Kp/fs-Kab)*bf*wtb;
    z[0] = 0;
    /* Zero Shear */
    u = 0;
    while
      (sigh + sigs + Kab*(wt*hh+qe)*bf*z[0] - pp*z[0]*z[0]/2 + u > 0)
      { z[0] = z[0] + 0.05;
        if (gwt >= (telev - hh)) u = 0.0312*bf*(3*Kp/fs-Kab)*z[0]*z[0];
        else u = 0;
        if ( (gwt > telev - hh - z[0]) && (gwt < telev - hh) )
          { z[0] = 0;
            while (sigh + sigs + Kab*(wt*hh+qe)*bf*z[0] - pp*z[0]*z[0]/2 +
                      0.0312*bf*(3*Kp/fs-Kab)*z[0]-telev+hh+gwt)*(z[0]-telev+hh+gwt) > 0) z[0] = z[0] + 0.05; }
      v = z[0];
      /* Calculate Maximum Moment */ if (gwt <= (telev - hh - z[0])) u = 0;
    else
      { if (gwt >= telev - hh) u = 0.0104*bf*(3*Kp/fs-Kab)*v*v*v;
        else u = 0.0104*bf*(3*Kp/fs-Kab)*pow((v-telev+hh+gwt),3); }
    M[0] = sigh*(hh/3+v)+ sigs*(hh/2+v)+ Kab*bf*(hh*wt+qe)*v*v/2-
            pp*v*v/6 + u;
    S[0] = M[0]/2.4;  /* Calculate Section Modulus */
    v = 0;
    /* Calculate Depth of Embedment */
    u = 0;
    while (sigh*(hh/3+v)+sigs*(hh/2+v)+Kab*bf*(wt*hh+qe)*v*v/2-
            pp*v*v/6 + u > 0) { v = v + 0.05;
      if (gwt >= (telev - hh)) u = 0.0104*bf*(3*Kp/fs-Kab)*v*v*v;
      else u = 0;)
      if (((gwt > telev - hh - v) && (gwt < telev - hh) ) { v = 0;
        while (sigh*(hh/3+v)+ sigs*(hh/2+v)+ Kab*bf*(hh*wt+qe)*v*v/2-
                  pp*bf*v*v/6 + 0.0104*bf*(3*Kp/fs-Kab)*pow((v-telev+hh+gwt),3)
Calculate Moment based on Kiewit Analysis

\[ M(0) = Ka*qe*hh*s*(hh/2+2)+Ka*wt*hh*hh*s*(hh/3+2)/2; \]
\[ D[0] = Ka*qe*hh*s*(hh/2+2)+Ka*wt*hh*hh*s*(hh/3+2)/2; \]

**STAGE II - SANDS**

```
if (numa) { ++i;
j = 1; v = 0; y = 0;
if (numa == 1) hh = belev;
else hh = anc[j] - w;
ka_kp();
strip();
```

```c
hh = telev - hh;
sigh = Ka*wt*s*hh*hh/2; /* Horizontal Stress due to Soil */
sigs = Ka*qe*s*hh; /* Horizontal Stress due to Surcharge */
```

```c
pp = (3*Kp/fs-Kab)*wt*bef;
v = 0;
u = 0;
while (sigh + sigs + Kab*(hh*wt+qe)*bef*v - pp*v*v/2 + u > 0) {
v = v + 0.05;
if (gwt >= (telev - hh )) u = 0.0312*bef*(3*Kp/fs-Kab)*v*v;
else u = 0;
}
if ( (gwt > telev - hh - v) && (gwt < telev - hh ) )
{ v = 0; u = 0;
while (sigh + sigs + Kab*(hh*wt+qe)*bef*v - pp*v*v/2 + 0.0312*bef*(3*Kp/fs-Kab)*(v-telev+hh+gwt)*(v-telev+hh+gwt) > 0)
  v = v + 0.05; }
```

```c
/* Reaction Force */
if (gwt <= (telev - hh - v)) { u = 0; }
else
{ if (gwt >= telev - hh ) { u = 0.0104*bef*(3*Kp/fs-Kab)*v*v*v; }
else { u = 0.0104*bef*(3*Kp/fs-Kab)*pow((v-telev+hh+gwt),3); } }
```

```c
R[0][0] = (sigh*(hh/3+v) + sigs*(hh/2+v) + Kab*(wt*hh+qe)*bef*v*v/2
- pp*v*v*v/6 + u) / (hh+anc[0]-telev+v);
v = 0; u = 0; /* Zero Shear */
while (R[0][0] - sigh - sigs - Kab*(wt*hh+qe)*bef*v + pp*v*v*bf/2
- u < 0 ) { v = v + 0.05;
if (gwt >= (telev - hh )) u = 0.0312*bef*(3*Kp/fs-Kab)*v*v;
else u = 0;
}
if ( (gwt > telev - hh - v) && (gwt < telev - hh ) ) { v = 0;
while ( R[0][0] - sigh - sigs - Kab*(wt*hh+qe)*bef*v + pp*v*v*bf/2
- 0.0312*bef*(3*Kp/fs-Kab)*(v-telev+hh+gwt)*(v-telev+hh+gwt) < 0)
  v = v + 0.05; }
z[1] = v;
```
if (gwt <= (telev - hh - v)) { u = 0; } // Maximum Moment
else
{ if (gwt >= telev - hh) u = 0.0104*bf*(3*Kp/fs-Kab)*v*v*v;
else u = 0.0104*bf*(3*Kp/fs-Kab)*pow((v-telev+hh+gwt),3); }
M[1] = sigh*(hh/3+z[1]) + sigs*(hh/2+z[1]) +
Kab*(2*hh+qe)*bf*z[1]*z[1]/2 - pp*z[1]*z[1]*z[1]/6 -
R[0][0]*(hh-telev+anc[0]+z[1]) + u; S[1] = M[1]/2.4;
// Section Modulus
D[1] = 0; u = 0; // Depth of Embedment */
while (M[1] - Ka*(qe+(telev-anc[0])*wt)*pow((hh-
telev+anc[0]),2)*s/2 - s*Ka*wt*pow((hh-telev+anc[0]),3)/3 -
bf*Kab*(qe+hh*wt)*D[1]*(D[1]/2+hh-telev+anc[0]) +
pp*D[1]*D[1]/2*(2*D[1]/3+hh-telev+anc[0]) - u < 0 )
{ D[1] = D[1] + 0.05;
if (gwt >= (telev - hh ))
u = 0.0312*bf*(3*Kp/fs-Kab)*D[1]*D[1]*(2*D[1]/3+hh-telev+anc[0]);
else u = 0; }
if ((gwt > telev - hh - D[1]) && (gwt < telev - hh) ) { D[1] = 0;
while ( M[1] - Ka*(qe+(telev-anc[0])*wt)*pow((hh-
telev+anc[0]),2)*s/2 - s*Ka*wt*pow((hh-telev+anc[0]),3)/3 -
bf*Kab*(qe+hh*wt)*D[1]*(D[1]/2+hh-telev+anc[0]) +
0.0312*bf*(3*Kp/fs-Kab)*pow((D[1]-telev+hh+gwt),2)*
(D[1]+hh-telev+anc[0])-(D[1]-telev+hh+gwt)/3) < 0)
D[1] = D[1] + 0.05; }
if (gwt >= (telev - hh ))
u = 0.0312*bf*(3*Kp/fs-Kab)*D[1]*D[1]*(2*D[1]/3+hh-telev+anc[0]);
else u = 0; }
D[1] = D[1] + 0.05;
// Calculate Moment & Reaction based on
Kiewit y = hh-telev+anc[0];
Mk[1] = Ka*s*y*y*(qe+wt/2*(hh+telev-anc[0]))/9;
Rk = Ka*qe*s*(telev-anc[0]) + Ka*wt*s*pow((telev-anc[0]),2)/2 +
(Ka*s*y*y/2*(qe+wt*(telev-anc[0])) + y*y*y*Ka*s*wt/6)/y;
cout << "\n\tSTAGE 2 COMPLETED. ";

// *******************************************
// STAGE III - SANDS
// *******************************************

j = 2;
while (j <= numa) {
  v = 0; y = 0; // Average Unit Wt & Fricion
  Angle /* if (j < numa) hh = anc[j] - w; */
  else hh = belev;
  ka_kp();
  strip();
  sigs = Ka * qe; /* Horizontal Stress due to Surcharge */
  sigh = 0.65 * Ka * wt * (telev - hh);
  /* Horizontal Stress due to Soil */
  for (i = 0; i < 10; i++) { R[i][j-1] = 0; }
  for (k = 0; k < j; ++k) /* Calculate Reaction Forces */
{  if (k < j - 1)  H = anc[k+1];}  else  H = hh;
v = 0;
for ( i = 1; i <= k; ++i)  v = R[i-1][j-1] * (anc[i-1] - H) + v;
R[k][j-1] = (pow((telev-H),2)*(sigh+signs)*s/2 - v) / (anc[k]-H);
}  i = 0;
// Calculate point of Zero Shear
v = R[0][j-1];
while (v - (telev - anc[i]) * (sigh + signs) * s > 0 )
{  v = R[++i][j-1] + v;
if (i == j - 1)  break;  }
Z[j] = v / ((sigh + signs) * s);
v = 0;  // Calculate Maximum Moment */
i = 0;  M[j] = 0;
while (telev - anc[i] < Z[j])
{  v = R[i][j-1] * (Z[j] - telev + anc[i]);
  ++i;
M[j] = M[j] + v;
if (i == j)  break;  }
M[j] = M[j] - (sigh + signs) * s * z[j] * z[j] / 2;
S[j] = M[j]/2.4;
/* Calculate Depth of Embedment */
v = M[j];  min_D();  D[j] = y;
if (j == numa) {  Mmax = M[0];
for (i = 1; i <= numa; i++)  if (M[i] > Mmax)  Mmax = M[i];
v = Mmax;  min_D();  Dmin = y;  }
++j;
cout << "\n\t Stage " << j << " Completed. ";
}  

// *********************************************
/* CLAY ANALYSIS FUNCTION */
// * Execute analysis for clays. */
// *********************************************

void clay_analysis(void)
{
f = 0;  j = 0;

// *********************************************
/* STAGE I - CLAYS */
// *********************************************

if (numa) hh = anc[0] - w;
else hh = belev;
float hhh = telev - hh;
wt_c_cbo();  // Calculate Average unit wt, c, and c base */
strip();
z_t = (2*ca-qe)/wt;  // Depth of Tension Zone */
if ((6/fs*cb+2*cb-qe-wt*(telev-hh) < 0))
\[ v = \frac{(6*cb/fs+2*cb-qe)}{wt}; \]
printf("\n\n\nERROR - Soil will not support the wall below a
depth of %4.2f feet.", v);
z[0] = -1; goto Q; }
if ((hh >= telev - zt) && (zt >= 0))
{ M[0] = 0; z[0] = 0; S[0] = 0; D[0] = 0; }
if ((hh < telev - zt) && (zt >= 0))
{
  sigh = s*(wt*hhh+qe-2*ca)*(hhh-zt)/2; /* Active Pressure */
  z[0] = sigh / pp; /* Zero Shear */
  M[0] = sigh*((hhh-zt)/3+z[0]) - pp*z[0]*z[0]/2; /* Max. Moment
  D[0] = 0; /* Depth of Embedment */
while (sigh*((hhh-zt)/3+D[0])-pp*D[0]*D[0]/2 > 0) D[0] = D[0] + 0.05;
z[0] = z[0] + hhh; }
if (zt < 0) {
  pp = (6*cb/fs+2*cb-wt*hhh-qe)*bf /* Resultant Resist Pres */
  z[0] = ((qe-2*ca)*hhh*s + wt*hhh*hhh/2*s) / pp; /* Zero Shear */
  // Max. Moment
  M[0] = (qe-2*ca)*hhh*s*(hhh/2+z[0]) + wt*hhh*hhh/2*s*(hhh/3+z[0])
  - pp*z[0]*z[0]/2;
  D[0] = 0; /* Depth of Embedment */
while (s*(qe-2*ca)*hhh*(hhh/2+D[0]) + wt*hhh*hhh/2*s*(hhh/3+D[0])
  - pp*D[0]*D[0]/2 > 0) D[0] = D[0] + 0.05;
z[0] = z[0] + hhh; }
S[0] = M[0]/2.4;
// Kiewit Analysis
Mk[0] = 0;
if (zt < 0) Mk[0] = s*wt*hhh*hhh/2*(hhh/3+2) +
  s*(qe-2*ca)*hhh*(hhh/2+2);
if ((zt >= 0) && (zt < hhh))
Mk[0] = s*(wt*hhh+qe-2*ca) * (hhh-zt)/2 * ((hhh-zt)/3+2);
Dmin = 7; Kp = zt;
// Set zt, stage 1 equal to Kp to compare to zt, stage 2
cout << "\n\n\nSTAGE I COMPLETE."
// *************************************************************/
// * STAGE II - CLAYS
// *************************************************************/
if (numa) {
  j = 1;
  if (numa == 1) hh = belev;
  else hh = anc[1] - w;
  strip();
  zt = (2*ca-qe)/wt;
  if (zt > Kp) zt = Kp;
  hhh = telev-hhh;
}
if ((6/fs*cb+2*cb-qe-wt*(telev-hh) < 0))
{ v = (6*cb/fs+2*cb-qe)/wt;
 printf("\a\n\n\nERROR - Soil will not support the wall below a
 depth of %4.2f feet.", v);
 z[0] = -1; goto Q; }
if ((hh > telev - zt) && (zt >= 0))
{ M[1] = 0; z[1] = 0; R[0][0] = 0; S[1] = 0; D[1] = 0; Rc = 0;
 M[0] = 0; }
if ((hh < telev - zt) && (zt >= 0))
{ hh = telev - hh;
sigh = s*(wt*hh+qe-2*ca)*hh-zt)/2;
 pp = (6*cb/fs+2*cb-wt*hh-qe)*bf;
 v = sigh / pp; /* Zero Earth Forces */
 R[0][0] = (sigh*((hh-zt)/3+v) - pp*v*v/2) / (hh-telev+anc[0]+v);
z[1] = (sigh - R[0][0]) / pp; /* Zero Shear */
 M[1] = sigh*(((hh-zt)/3+z[1]) - pp*z[1]*z[1]/2 - R[0][0]*(hh
-telev+anc[0]+z[1]); D[1] = 0;
 if (anc[0] > telev-zt) 
 while (M[1] + pp*D[1]*D[1]/2+hh-telev+anc[0]) - sigh *
 (hh+anc[0]-telev-(hh-zt)/3) < 0)
 D[1] = D[1] + 0.05; }
else 
 while (M[1] + pp*D[1]*D[1]/2+hh-telev+anc[0]) - 
 s*(qe-2*ca+wt*(telev-anc[0]))* pow((hh-telev+anc[0]),2)/2 - 
 s*wt*pow((hh-telev+anc[0]),3)/3 < 0)
 D[1] = D[1] + 0.05; }
 z[1] = z[1] + hh; }
if (zt < 0) { hh = telev - hh;
 pp = (6*cb/fs+2*cb-wt*hh-qe)*bf;
 sigh = s*wt*hh*hh/2;
sigs = s*(qe-2*ca)*hh;
v = (sigh + sigs) / pp;
 R[0][0] = (sigh*(hh/3+v) + sigs*(hh/2+v) - pp*v*v/2) / (hh
-telev+anc[0]+v);
z[1] = (sigh + sigs - R[0][0]) / pp;
 M[1] = sigh*(hh/3+z[1]) + sigs*(hh/2+z[1]) - pp*z[1]*z[1]/2 - 
 R[0][0]*(hh-telev+anc[0]+z[1]);
 D[1] = 0;
 while (M[1] + pp*D[1]*D[1]/2+hh-telev+anc[0]) - 
 s*(qe-2*ca+wt*(telev-anc[0]))* pow((hh-telev+anc[0]),2)/2 - 
 s*wt*pow((hh-telev+anc[0]),3)/3 < 0)
 D[1] = D[1] + 0.05;
 z[1] = z[1] + hh; }
 S[1] = M[1]/2.4;

H = hhh-zt; // Kiewit Analysis
 v = telev - anc[0];
 y = hhh-telev+anc[0];
 MK[1] = Rk = 0;
 if (zt < 0) { Mk[1] = s*y*y*(qe - 2*ca + wt*v + wt*y/2)/9;
\[ R_k = s*(q_e-2*ca)*v + s*wt*v*v/2 + s*((q_e-2*ca+wt*v)*y/2 + wt*y*y/6); \]
\[
\text{if } ((zt >= 0) \&\&(zt >= y)) \&\&(zt < hhh)) \{ \\
Mk[1] = s*y*y/9 *(q_e-2*ca+wt*hhh)*h/(2*y); \\
Rk = s*(wt*hhh+q_e-2*ca)*h*h/(6*y); \} \\
\text{if } ((zt >=0) \&\&(zt < y)) \{ \\
Mk[1] = s*y*y/9 *(q_e - 2*ca + wt*v + wt*y/2); \\
Rk = s*((q_e-2*ca+wt*v)*(v-zt)/2 + (q_e-2*ca+wt*v)*y/2 + wt*y*y/6); \\
\}
\]

```
// ************************************************************
// * STAGE III - CLAYS
// ************************************************************
if (numa > 1) {
    j = 2;
    while (j <= numa) {
        double a, h;
        if (j < numa) hh = anc[j] - w;
        else hh = belev;
        wt_c_cb();
        strip();
        if (((6/fs*cb+2*cb-qe-wt*(telev-hh) < 0))
            v = (6*cb/fs+2*cb-qe)/wt;
        printf("\n\n\nERROR - Soil will not support the wall between a 
    depth of %4.2f feet.", v);
        z[0] = -1; goto Q;
    }
    float Ns = wt*(telev-hh)/ca; /* Stability Number */
    for (i = 0; i < 10; i++) R[i][j-1] = 0;
    for (k = 0; k < j; k++) {
        if (k < j - 1) H = anc[k+1];
        else H = hh;
        h = telev - hh;
        a = telev - H;
        v = 0;
        if (gwt > H) u = 0.0104*pow((gwt-H),3)*s;
        else u = 0;
        for (i = 1; i <= k; i++) v = R[i-1][j-1] * (anc[i-1] - H) + v; if (Ns <= 6)
            { if (a < h/4) sigh = 1.6*wt*pow(a,3)/6;
                if ((a >= h/4) && (a <= 3*h/4)) sigh = 0.05*wt*h*h*(a-h/6) + 0.2*wt*h*pow((a-h/4),2);
                if (a > 3*h/4) sigh = wt*pow(h,2)*(0.05*(a-h/6) + 0.2*(a-h/2))
                    + 0.4*wt*pow((-0.75*h),2)*(h-2*a/3); }
                if (Ns > 6)
                    { Ka = 1 - 4*ca/(wt*h);
                        if (a < h/4) sigh = 2*Ka*wt*a*a/a/3;
                        else sigh = Ka*wt*h*h/8*(a-h/6) + Ka*wt*h*pow((a-h/4),2)/2; }
                R[k][j-1] = (s*qe*pow((telev-H),2)/2 + s*sigh - v + u) /
```
v = 0; /* Calculate point of Zero Shear */
for (i = 0; i < numa; i++) v = R[i][j-1] + v;
if (Ns <= 6) {
    while (v + 0.05*wt*h*h*s - (qe+0.4*wt*h)*s*z[j] - u > 0) {
        v = z[j] + 0.05;
        if (telev - z[j] <= gwt) u = 0.0312*s*pow((z[j]-telev+gwt),2); }
        if (z[j] > 3*h/4) {
        z[j] = z[j] + 0.05;
        if (telev-z[j] <= gwt) u = 0.0312*s*pow((z[j]-telev+gwt),2); } }
        v = 0; /* Calculate Maximum Moment */
M[j] = 0;
for (i = 0; i < j; ++i) {
    v = R[i][j-1] * (z[j] - telev + anc[i]);
M[j] = M[j] + v; }
if (Ns <= 6) {
    if (z[j] <= 3*h/4) sigh = 0.05*wt*h*h*(z[j]-h/6) + 
0.2*wt*h*pow((z[j]-h/4),2);
else sigh = 0.05*wt*h*h*(z[j]-h/6) + 0.2*wt*h*h*(z[j]-h/2) + 
0.4*wt*pow((z[j]-.75*h),2)*h-2*z[j]/3; }
else sigh = Ka*wt*h*h/8*(z[j]-h/6) + Ka*wt*h*pow((z[j]-h/4),2)/2;
if (gwt > telev-z[j]) u = 0.0104*s*pow((z[j]-telev+gwt),3);
else u = 0;
M[j] = M[j] - qe*s*z[j]*z[j]/2 - sigh*s - u;
S[j] = M[j]/2.4; /* Calculate Depth of Embedment */
D[j] = 0;
if (Ns <= 6) {
    if (anc[j-1] >= telev-3*h/4) sigh = 0.4*wt*h*pow((.75*h-telev+anc[j-1]),2)/2 + 
0.05*wt*h*h*(5*h/6-telev+anc[j-1]);
else sigh = 0.8*wt*(h-telev+anc[j-1]) * 
pow((h-telev+anc[j-1]),2)/3; }
else sigh = Ka*wt*h*pow((anc[j-1]-hh),2)/2;
if (gwt >= anc[j-1]) u = 0.0312*(gwt-anc[j-1])*pow((anc[j-1]-hh),2)*s + 
0.0208*pow((anc[j-1]-hh),3)*s;
if ((gwt > hh) || (gwt < anc[j-1])) u = 0.0312*pow((gwt-hh),2)*(anc[j-1]-hh-(gwt-hh)/3)*s;
if (gwt <= hh) u = 0;
while (M[j] + (6*cb/fs+2*cb-qe)*bf*D[j]*(D[j]/2+(anc[j-1]-hh)) - sigh*s - s*qe*pow((anc[j-1]-hh),2)/2 - u < 0)
D[j] = D[j] + 0.05;
++j;
cout << "\n\tSTAGE " << j << " COMPLETED. ";}
if (numa > 1) { Mmax = M[0];
for (i = 1; i <= numa; i++)
if (M[i] > Mmax) Mmax = M[i]; Dmin = 0;
while (Mmax + (6*cb/fs+2*cb-ge)*bf*Dmin*(Dmin/2+(anc[j-2]-hh))
- sigh*s - s*ge*pow((anc[j-2]-hh),2)/2 - u < 0)
Dmin = Dmin + 0.05; }
Q: i = 0;

// ******************* KA_KP FUNCTION
// * Cal. average unit weight, friction angle, and Ka for cut.
// * Calculate unit weight, friction, Ka, and Kp for base soil.
// *******************

void ka_kp(void) {
for (k = 0; hh < soil[k+1][0]; ++k)
if (k >= (nums-1)) break;
v = soil[k][1] * (soil[k][0] - soil[k+1][0]) + v;
y = soil[k][2] * (soil[k][0] - soil[k+1][0]) + y;
v = v + soil[k][1] * (soil[k][0] - hh);
y = y + soil[k][2] * (soil[k][0] - hh);
wt = v / (telev - hh);
fa = y / (telev - hh);
l = nums - 1;
while (hh > soil[1][0]) --l;
fab = soil[l][1];
wtb = soil[l][1];
Kp = pow(tan((45 + fab/2)*pi/180),2); /* Calculate Ka & Kp */
Kab = pow(tan((45 - fab/2)*pi/180),2);
if (b == 0) { Ka = pow(tan((45 - fa/2)*pi/180),2); }
else { Ka = pow(cos(fa*pi/180),2)/(cos(fa*pi/270)*pow(l+sqrt
(sin(fa*pi/108)*sin((fa*pi/180)/(cos(fa*pi/180) *
cos(b*pi/180))),2)),2); }

// ******************* MIN_D FUNCTION
// * Calculate min. embedment depth for stage III of sand excav.
// *******************

void min_D(void) { u = y = 0;
while (v + Kp/fs*1.5*wtb*bf*y*y*(2*y/3-hh+anc[j-1])
( sigh+signs)*(anc[j-1]-hh)*(anc[j-1]-hh)*s/2 - u < 0)
{ y = y + 0.05;
if (gwt >= hh) u = 0.0936*bf*Kp/fs*y*y*(2*y/3-hh+anc[j-1]);
else u = 0; }
if ((gwt > hh - y) && (gwt < hh) ) { y = 0;
while (v + Kp/fs*1.5*wtb*bf*y*y*(2*y/3-hh+anc[j-1]) - 93
(sigh+sigs)*(anc[j-1]-hh)*(anc[j-1]-hh)*s/2 - 0.0936*bf*
Kp/fs*pow((y-hh+gwt),2)*(y-hh+anc[j-1]-(y+gwt-hh)/3) < 0)
y = y + 0.05; } }

// ***Calculate average unit weight and cohesion for cut.
// Also calculate average cohesion for base soils.
void wt_c_cb(void) {
  Ka = 1; 
v = 0; y = 0;
for (k = 0; hh < soil[k+1][0]; ++k)
  if (k >= (nums-1)) break;
v = soil[k][1] * (soil[k][0] - soil[k+1][0]) + v;
y = soil[k][2] * (soil[k][0] - soil[k+1][0]) + y;
v = v + soil[k][1] * (soil[k][0] - hh);
y = y + soil[k][2] * (soil[k][0] - hh);
  if (str_anal == 1) u = 0;
else { if ((gwt > hh) && (j < 2)) u = 0.0624*(gwt-hh);
else u = 0; }
w = (v + u) / (telev - hh);
c = y / (telev - hh);

// Calculate the average cohesion over 20 ft.

ij = jk = nums-1;
while (soil[jk][0] < hh-20) --jk;
while (soil[ij][0] < hh) --ij;
if (ij == jk) cb = soil[ij][2];
else { y = 0; v = hh;
while (ij < jk) {
v = v - soil[ij+1][0];
y = v * soil[ij][2] + y;
v = soil[++ij][0]; }
}
}

void strip(void) {
double O1 = atan(qs[2]/(telev-hh));
double O2 = atan((qs[1]+qs[2])/(telev-hh));
qe = 2*qs[0]/(pi*Ka)*(O2-O1) + q; }
/*Perform analysis for wale section modulus, and bonded and */unbonded length for tieback anchor.

void anchor(void) {
    clrscr();
    cout << "Enter the spacing of the anchors. -- ";
    cin >> d;
    cout << "Enter the angle of the anchors. -- ";
    cin >> ang;
    cout << "Select soil type:
	 Type Soil Description SPT N Value
	 1 Fine to medium sand 12 - 30"
	 2 Medium to coarse sand 20 - 45"
	 3 Sandy Gravel > 45"
	 4 Medium Clay 9 - 11"
	 5 Stiff Clay 12 - 15"
	 6 Stiff to Very Stiff Clay 16 - 20"
	 7 Very Stiff Clay 21 - 30"
	 8 Very Stiff to Hard Clay > 30"
}

while ((type = atoi(gets(cc))) <= 0 || type >= 10)
    { cout << " " << cc << " is an incorrect response. a";
      cout << "Reenter soil type. - ";
    }
    for (i = 0; i < numa; ++i) { /* Cal. Wale Section Modulus */
        v = 0;
        for (j = 0; j < numa; ++j) { if (v < R[i][j]) v = R[i][j]; }
        sw[i] = v * d * d / (14.4 * s);
        P[i] = v * d / (s * cos(ang*pi/180)); /* Cal. Anchor Length
        switch (type) {
            case 1: L[i] = pow(10,((P[i]+68.9)/147)); break;
            case 2: L[i] = pow(10,((P[i]+74.5)/182.4)); break;
            case 3: L[i] = pow(10,((P[i]+144.2)/298.2)); break;
            case 4: L[i] = P[i]/3.14; break;
            case 5: L[i] = P[i]/4.71; break;
            case 6: L[i] = P[i]/6.28; break;
            case 7: L[i] = P[i]/7.85; break;
            case 8: L[i] = P[i]/9.42; break;
            case 9: L[i] = P[i]/11.0; break;
        }
        /* Calculate Unbonded Length */
        ul[i] = ((anc[i]-belev)/sin((45 + ang + fa/2)*pi/180)) * sin((45 - fa/2)*pi/180);
    }
    clrscr();
    cout << "OUTPUT FROM WALE AND ANCHOR ANALYSIS
    Spacing of the anchors is " << d << " feet."
    cout << "The anchors are set at an angle of " << ang << " degrees."
The anchors are set in "

switch (type) {
    case 1: cout << "fine to medium sand."; break;
    case 2: cout << "medium to coarse sand."; break;
    case 3: cout << "sandy gravel."; break;
    case 4: cout << "medium clay."; break;
    case 5: cout << "medium stiff clay."; break;
    case 6: cout << "stiff clay."; break;
    case 7: cout << "stiff to very stiff clay."; break;
    case 8: cout << "very stiff clay."; break;
    case 9: cout << "very stiff to hard clay."; break;
}

printf("\n\n ANCHOR SECTION MODULUS ANCHOR UNBONDED\n\n ROW OF WALE (in³) CAPACITY (kips)\n LENGTH (ft) LENGTH (ft)\n %2d %4.1f %4.1f %4.1f %4.1f", i, sw[i-1], P[i-1], L[i-1], ul[i-1]);

if ((type >=1) && (type <= 3))
    cout << "\n\nNOTE: Tieback capacity is based on pressure injected anchors using an"
    <<"\n effective grout pressure in excess of 150 psi with a diameter" <<"\n between 4 to 6 inches and depth of overburden greater than 13 feet.";
else
    cout << "\n\nNOTE: Tieback capacity is based on post-grouted anchors using an effective"
    <<"\n grout pressure in excess of 150 psi with a diameter of six inches.";

for (i = 0; i < numa; ++i) { if (ul[i] < 15){
    cout << "\n\nNOTE: FHWA/RD-82/047 recommends a minimum unbonded length of 15 feet."; break; }
    bp = 3;
    cout << "\n\nPress the enter key to return to the main menu.\n";
    gets(cc); }

// *****************************************************************************
// * SAVE FUNCTION
// * Save the results from the various analysis functions.
// *****************************************************************************

void save(void) {
    FILE *xp;
    clrscr();
    cout << "\n\nEnter filename to save the data. -- ";
    gets(filename);
    while ((xp=fopen(filename,"r")) != NULL) {
        cout << "\n\nThe file already exits, do you want to overwrite it? (Y/N) -- \
";
    }
    // *** save data to file ***
    xp = fopen(filename,"w+"); // open file for writing
    if (xp == NULL) {
        cout << "\n\nThe file couldn't be opened for writing. Please check the filename.
";
        return;
    }
    // write data to file
    fwrite(&data, sizeof(data), 1, xp);
    fclose(xp);
    xp = NULL;
    cout << "\n\nThe data has been saved to the file.\n";
}

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gets(cc);
c = toupper(cc[0]);
switch (c) {
case 'Y': break;
case 'N': clrscr();
cout << "\n\tReenter the filename. -- ";
gets(filename); break;
default:
cout << "\n\t" << cc << " is an incorrect response, try again. -- \a"
gets(cc);
c = toupper(cc[0]); }
if (c == 'Y') { c = 'x'; break; }
xp = fopen(filename, "w+");
fprintf(xp, "\n\n\t*******************************************\nfather (xp, "\n\tDesign of Soldier Pile and Lagging *
father (xp, "\n\tIn Accordance with NAVFAC DM-7 *
father (xp, "\n\t*******************************************\nfather (xp, "\n\tI. W A L L P R O P E R T I E S\nfather (xp, "\n\t1. Engineer: %s", engineer);
father (xp, "\n\t2. Project: %s", project);
father (xp, "\n\t3. Date: %s", date);
father (xp, "\n\t4. The elevation of the top of the excavation
father (xp, "\n\t5. The elevation of the bottom of the
father (xp, "\n\t6. The number of anchors is %d.", numa);
if (numa) {
fprintf(xp, "\n\tThe anchors are located as follows:\nfather (xp, "\n\tAnchor\tElevation (feet)\nfather (xp, "\n\t7. The spacing of the soldier piles is %3.2f feet.", s);
fprintf(xp, "\n\tII. S O I L P R O P E R T I E S");
fprintf(xp, "\n\t8. The elevation of the water table is %6.2f feet.", gwt);
fprintf(xp, "\n\t9. The soil properties are as follow:\nfather (xp, "\n\tSoil Type Elev Unit Wt
Friction Angle
fprintf (xp, "\n\t or Cohesion") ; j = 0;
for (i = 0; i < nums; ++i) {
    fprintf (xp, "\n\t ");
    if (soil_type == 1) fprintf (xp, "sand");
    else fprintf (xp, "clay");
    fprintf (xp, "%7.2f %1.4f %5.2f",
        soil[j][0], soil[j][1], soil[j][2]);
    j++;
}
fprintf (xp, "\n\t10. The slope of the ground behind the wall is %2.2f degrees.", b);
fprintf (xp, "\n\t11. The surcharge load is %3.3f ksf.", q);
fprintf (xp, "\n\t12. The strip load is %7.2f ksf, %4.2f feet wide,", q[0], q[2]);
fprintf (xp, "\n\t and located %5.1f feet from the wall.", q[2]);
fprintf (xp, "\n\tIII. WALL ANALYSIS RESULTS");
fprintf (xp, "\n\t13. Estimated width of the soldier pile is %3.2f feet.", b);
fprintf (xp, "\n\t14. Factor of safety for passive resistance is %3.1f.", fs);
fprintf (xp, "\n\t15. The wall was excavated %3.1f feet below the proposed anchor location.", w);
fprintf (xp, "\n\t16. STAGE ZERO MAXIMUM SECTION EMBEDMENT REACTION(S)");
fprintf (xp, "\n\t SHEAR MOMENT MODULUS DEPTH");
fprintf (xp, "\n\t (ft) (k-ft) (in^3) (ft) (kips)");
fprintf (xp, "\n\t-----------------------------------------------");
for (i = 2; i <= numa + 1; ++i) {
    fprintf (xp, "\n\t %6.1f %6.2f %6.2f %6.1f ",
        z[i-1], M[i-1], S[i-1], D[i-1], R[i-1][j]);
    if (R[i-1][j]) {
        fprintf (xp, "%d = ", k);
        fprintf (xp, "%6.2f", R[i-1][j]);
    }
}
fprintf(xp, "\n\n\tNOTE: Stage 1 moment based on Kiewit criteria is %6.1f kip-ft.", Mk[0]);
if (numa > 0) {
    fprintf(xp, "\n\tStage 2 moment based on Kiewit criteria is %6.1f kip-ft", Mk[1]);
fprintf(xp, "\n
 and reaction force is %6.1f kips.", Rk);
if (numa > 1)
fprintf (xp, "\n\n NOTE: Minimum depth of embedment based on
 maximum moment is %3.1f feet.", Dmin);
if ((D[numa] < 6) && (Dmin < 6)) {
fprintf (xp, "\n\n NOTE: NYCTA recommends minimum penetration
depth of six feet."); }
if ((soil_type == 2) && (str_anal == 1))
fprintf (xp, "\n\n NOTE: A total stress analysis approach was
 used.");
if ((soil_type == 2) && (str_anal == 2))
fprintf (xp, "\n\n NOTE: NYCTA recommends minimum penetration
depth of six feet.");
if (bp > 2) {
fprintf (xp, "\n\n IV. ANCHOR AND WALES
 ULTS ");
fprintf (xp, "\n\n NOTE: An effective stress analysis approach
 was used.");
fprintf (xp, "\n\n l7. Spacing of the anchors is %3.1f feet.", d);
fprintf (xp, "\n\n l8. The anchors are set at an angle of %3.1f
 degrees.", ang);
fprintf (xp, "\n\n l9. The anchors are set in ");
switch (type) {
case 1: fprintf (xp, "fine to medium sand."); break;
case 2: fprintf (xp, "medium to coarse sand."); break;
case 3: fprintf (xp, "sandy gravel."); break;
case 4: fprintf (xp, "medium clay."); break;
case 5: fprintf (xp, "medium stiff clay."); break;
case 6: fprintf (xp, "stiff clay."); break;
case 7: fprintf (xp, "stiff to very stiff clay."); break;
case 8: fprintf (xp, "very stiff clay."); break;
case 9: fprintf (xp, "very stiff to hard clay."); break; }
fprintf (xp, "\n\n \n ANCHOR SECTION MODULUS ANCHOR
 ROW OF WALE (in^3) CAPACITY (kips)
 LENGTH (ft) LENGTH (ft)");
printf (xp, "\n ---------------------------------------------------------------

 for (i = 1; i <= numa; ++i) {
fprintf (xp, "\n %2d  %4.1f  %4.0f
 %4.1f  %4.1f", i, sw[i-1], P[i-1], L[i-1], ul[i-1]);
if ((type >=1) && (type <= 3)) {
fprintf (xp, "\n\n NOTE: Tieback capacity is based on pressure
 injected anchors using an");
fprintf (xp, "\n\n effective grout pressure in excess of
 150 psi with a diameter");
fprintf (xp, "\n\n between 4 to 6 inches and depth of
 overburden greater than 13 feet.");
}
else {
    fprintf (xp, "\n\n NOTE: Tieback capacity is based on post
-grouted anchors using an effective");
    fprintf (xp, "\n grout pressure in excess of 150 psi
with a diameter of six inches.")); }
for (i = 0; i < numa; ++i) { if (ul[i] < 15) {
    fprintf (xp, "\n\n NOTE: FHWA/RD-82/047 recommends a minimum
unbonded length of 15 feet.")); break; } }
    fprintf (xp, "\n\n\t\t\tE N D 0 F A N A L Y S I S");    
    fprintf (xp, "\n\n");    
    fclose(xp);
    cout << "\n\tData saved, press the enter key to return to the
main menu. "; gets(cc);
//  ************************************************************************************************************
//  *       END OF PROGRAM
//  ************************************************************************************************************
    
}
APPENDIX C

CALCULATIONS AND EQUATIONS
Sands:

\[ K_a = \tan^2(45 - \phi/2) \quad \text{- Level Backfill} \]

\[ K_a = \frac{\cos^2(\phi - \theta)}{\cos^2 \theta \cos(\theta + \delta) \left[ 1 + \sin(\theta + \delta) \sin(\phi - \theta) / \cos(\theta + \delta) \cos(\phi - \theta) \right]^2} \]

For sloped backfill where,

\( \phi \) - Friction angle
\( \theta \) - Inclination of wall
\( \beta \) - Slope of backfill
\( \delta \) - Friction angle between pile & soil

Setting \( \theta = 0^\circ \) and \( \beta = 2/3 \phi \), \( K_a \) can be reduced to

\[ K_a = \frac{\cos^2 \phi}{\cos(2 \phi/3) \left[ 1 + \sin(2 \phi/3) \sin(\phi - \theta) / \cos(2 \phi/3) \cos(\phi - \theta) \right]^2} \]

Failure Surface = 45° + \( \phi/2 \)

\[ K_p = \tan^2(45 + \phi/2) \]

Therefore,

\[ \sigma_a = K_a YZ \quad \sigma_p = K_a YH^2/2 \quad \sigma_b = K_a q \]

\[ \sigma_p = K_p YZ \quad \text{Passive resistance acts on Zbf} \]

Stage I:

Zero shear: \( \Sigma V = 0 = K_a Y H_f^2/2 \times S + K_a q H_f S + K_a b (8H_f + q) \times Z - (3K_b/f_s - K_a b) \times 6 \times Z^2/2 \)

Solve for \( Z \).

Max Moment, \( \Sigma M = K_a q H_f^2/2 \times S(1/3 + Z) + K_a q H_f S(1/2 + Z) + K_a b (8H_f + q) \times Z^3/2 - (3K_b/f_s - K_a b) \times 6 \times Z^3/6 \)
STAGE III: 2 OR MORE ANCHOORS.

\[ \sigma_t = 0.65 \sigma_a \gamma \]

**REACTION FORCES**

\[ \Sigma M_{R_2} = R_1 \epsilon (A_2 - A_1) - (\sigma_t + K_a q) S A_2^2 / 2 = 0 \]

\[ R_1 = \frac{[S (\sigma_t + K_a q) A_2^2]}{2 (A_2 - A_1)} \]

**SIMILARLY, R_2 = \frac{[S (\sigma_t + K_a q) H_3^2 / 2 - R_1 (H_3 - A_1)]}{(H_3 - A_2)}**

**OR**

\[ R_1 = \frac{[S (\sigma_t + K_a q) A_2^2 / 2 - \sum_{i=1}^n (A_2^2 - A_1^2)]}{(A_1 - A_2)} \]

**ZERO SHEAR, \Sigma V = 0 = R_1 + R_2 - (\sigma_t + 9K_a) S E**

**OR**

\[ E = \frac{(R_1 + R_2)}{(\sigma_t + 9K_a) S} \]

**OR**

\[ E = \frac{\Sigma R_i}{(\sigma_t + 9K_a) S} \]

**MAX MOMENT, \Sigma M_2 = R_1 (E - A_1) + R_2 (E - A_2) - (\sigma_t + K_a q) S E^2 / 2**

**OR**

\[ E = \frac{\Sigma R_i}{(E - A_1)} - (\sigma_t + K_a q) S E^2 / 2 \]

**DEPTH OF EMBODIMENT, D**

\[ \Sigma M_2 = 0 = M_5 + 3K_a q \epsilon \sigma_3 (E - A_2) \]

\[ - (\sigma_t + 9K_a) S (E - A_2)^2 / 2 \]

**SOLVE FOR D.**
DEPTH OF EMBEDMENT: \( \Sigma M_0 = \Phi \)

\[
\Sigma M_0 = P_a \left( \frac{H_1}{3} + D \right) S + P_q \left( \frac{H_2}{2} + D \right) S + K_{36} \left( \phi + H_2 \right) b_1 D^2/2
\]

\[ - (3K_p/6 - K_{36}) b_1 \delta b D^3/6 = \Phi \]

SOLVE FOR \( D \).

STAGE II: 1 STRUT

POINT OF TWENTIETH NET PIECE ON EMBEDDED PILE AND ASSUME HINGED AT THAT POINT (ZERO MINUS-)

\[
\Sigma F_y = 0 = P_a * S + P_q * S + K_{36} b_1 \left( \phi + H_2 \right) x - (3K_p/6 - K_{36}) b_1 \delta b X^2/2\]

SOLVE FOR \( X \).

REACTION FORCE:

\[
R_1 = \left[ P_a S \left( H_2/3 + x \right) + P_q S \left( H_2/2 + x \right) + K_{36} b_1 \left( \phi + H_2 \right) x^2/2 - (3K_p/6 - K_{36}) b_1 \delta b x^3/6 \right] / \left( H_2 - \Delta_1 + X \right)
\]

ZERO SHEAR, \( \Sigma V = 0 = R_1 - P_a - P_q - K_{36} \left( \phi + H_2 \right) b_1 z + (3K_p/6 - K_{36}) b_1 \delta b z^2/2 \)

SOLVE FOR \( Z \).

MAX. MOMENT, \( \Sigma M = R_1 \left( H_1 - \Delta_1 + Z \right) + (3K_p - K_{36}) b_1 \delta b Z^3/6 - P_a \left( H_2/3 + Z \right) - P_q \left( H_2/2 + Z \right) - K_{36} \left( \phi + H_2 \right) b_1 Z^2/2 \)

DEPTH OF EMBEDMENT:

\[
\Sigma M_n = M_s + (3K_p - K_{36}) b_1 \delta b Z^2/2 \left( H_2 - \Delta_1 + 20/3 \right)
\]

\[ - K_{36} \phi H_2 (H_2 - \Delta_1)^3/3 - K_{36} \left( \phi + H_2 \right) \delta b \]

\[ D (D/2 + H_2 - \Delta_1) b_1 = \Phi \]

SOLVE FOR \( D \).

REQUIRED SECTION MODULUS, \( S = \frac{M}{\sigma_y} = \frac{M \times 12}{0.8 \times 36} \)

\[ S = \frac{M}{2.4} \text{ (in}^3) \], WHERE \( M \text{ N} \cdot \text{K} \cdot \text{F} \cdot \text{T} \)
CLAYS:

HEIGHT OF TENSION ZONE,
\[ z_t = \frac{(2c - q)}{\gamma} \]
WHERE \( 2c > q \)
ELSE \( z_t = 0 \).

\[ \sigma_A = \gamma z - 2c + q \]
\[ \sigma_D = \gamma z + 2c \]

NET PASSIVE RESISTANCE BELOW BOTTOM OF CUT:

DM-7 \( \rightarrow \) UNIFORM RESISTANCE OF \( 2c \times 3bf \)
WITH FACTOR OF SAFETY (fs)

\[ \sigma_p' = 6cbf/\text{fs} \]
\[ \sigma_A' = (q + \delta H - 2c) \times \text{bf} \]
NEGLECT SOIL RESISTANCE \( (\delta z) \)

NET PP = \( \sigma_p' - \sigma_A' = (6c/\text{fs} + 2c - q - H\delta) \times \text{bf} \)

IF \( 6c/\text{fs} + 2c < q + H\delta \), SOIL WILL NOT SUPPORT THE WALL.

STAGE I: NEGLECT TENSION ZONE

IF \( z_t > \text{Al} \rightarrow \sigma^* = \emptyset \)
IF \( z_t < \text{Al} \rightarrow \sigma_A = 3H + q - 2c \)

ZERO SHEAR, \( v = 0 = \sigma_A \times (H_1 - z_t)/2 \times S - PP Z \)

\[ Z = \sigma_A \times (H_1 - z_t) S / 2 \text{pp} \]
MAX MOMENT, \( \Sigma M_z = \sigma_a (H_1 - Z_t)/2 + S(\frac{H_1 - Z_t}{2} + \frac{H_2 - Z_t}{2} + \frac{H_3}{3} + D) - PP \times \frac{Z_t^2}{2} \)

DEPTH OF EMBEDMENT, \(D\)

\[ \Sigma M_D = 0 = \sigma_a (H_1 - Z_t) \times S/2 \times (\frac{H_1 - Z_t}{2} + D) - PP \times \frac{D^2}{2} \]

SOLVE FOR \(D\).

IF \(Z_t < 0 \rightarrow NO TENSION ZONE\)

ZERO SHEAR, \(\Sigma V = 0 = (q - 2c)H_1 S + S H_2 S/2 - PP \times Z_t \)

\[ Z_t = [(q - 2c)H_1 S + S H_2 S/2] / PP \]

MAX MOMENT, \( \Sigma M_z = (q - 2c)H_1 S (H_1/2 + Z_t) + S H_1/2 \times S (H_1/3 + Z_t) - PP \times \frac{Z_t^2}{2} \)

DEPTH OF EMBEDMENT, \( \Sigma M_D = 0 \)

\[ S(q - 2c)H_1 (\frac{H_1}{2} + D) + S H_1/2 \times S (H_1/3 + D) - PP \times \frac{D^2}{2} = 0 \]

SOLVE FOR \(D\).

STAGE II: \(Z_t > 0\) BUT \(Z_t < \) CUT BOTTM

NET ZERO FORCES ON EMBEDDED PILE, \(\Sigma F_Y = 0\)

\[ S (Y H_2 + q - 2c)(H_2 - Z_t)/2 - PP \times X = 0 \]

\[ X = S (8H_2 + q - 2c)(H_2 - Z_t)/2PP \]

REACTION FORCE, \(R_1 \rightarrow \Sigma M_b\)

\[ S (8H_2 + q - 2c)(H_2 - Z_t)/2 \times (\frac{8H_2 + q - 2c}{3} + X) - PP \times \frac{X^2}{2} - R_1 \times (H_2 - A_1 + X) = 0 \]

POINT OF ZERO SHEAR

\[ \Sigma V = 0 = S (8H_2 + q - 2c)(H_2 - Z_t)/2 - PP \times Z_t - R_1 \]

\[ Z_t = [S (8H_2 + q - 2c)(H_2 - Z_t)/2 - R_1] / PP \]
Max. Moment, $\Sigma M_z = S (qH_2 + q - 2c)(H_2 - z) / 2 \times (\frac{H_2 - z}{2} + z)$

\[-pp \times z^2 / 2 - R1 \times (H_2 - A1 + z)\]

Depth of Embedment

$\Sigma M_{ai} = \phi = M_5 + pp \times D \times (D/2 + H_2 - A1) -$

\[S \times (q - 2c + 5a1) \times (H_2 - A1)^2 / 2 -
2S \times 8 (H_2 - A1) ^{3/2} .\]

Solve for $D$

$z < \phi$

Net Zero Forces, $\Sigma F_y = S (qH_2 / 2) + S (q - 2c)H_2 - pp \times x - \phi .

X = [S \times H_2 / 2 + S (q - 2c)H_2] / pp$

Reaction Force, $\Sigma M_x = \phi .

R1 = [S \times H_2 / 2 (H_2 / 2 + x) + S(q - 2c)H_2(H_2 / 2 + x) - pp \times x^2 / 2] / (H_2 - A1 + x)$

Pt. of Zero Shear, $\Sigma V = \phi$

$z = [S \times H_2 / 2 + S (q - 2c)H_2 - A1] / pp$

Max. Moment, $\Sigma M_z = S \times H_2 / 2 \times (H_2 / 3 + z) + S(q - 2c)H_2(H_2 / 2 + z)$

\[-pp \times z^2 / 2 - R1 \times (H_2 - A1 + z)\]

Depth of Embedment, same as $z > \phi$ for Stage II.
STAGE III:

STABILITY NUMBER \( N_s = \frac{\gamma H \alpha}{c} \)

CASE A: IF \( N_s \leq 4 \) →
\[ T_h = \frac{1.05 z}{H} \quad \text{WHERE} \quad z < 0.25 \]
\[ T_h = 0.45 H \quad \text{WHERE} \quad H/9 \leq z < 3 H/4 \]
\[ T_h = 1.68 (H/2) \quad \text{WHERE} \quad z \geq 3 H/4 \]

CASE B: IF \( N_s > 6 \) →
\[ T_h = 9 K_{a0} z \quad \text{WHERE} \quad z < H/4 \]
\[ T_h = K_{as} H \quad \text{WHERE} \quad z \geq H/4 \]
\[ K_{as} = 1 - 4 MC/8 H \quad \text{WHERE} \quad M = 1. \]

IF \( N_s > 4 \) BUT \( N_s \leq 6 \) → USE LARGER OF TWO STRESSES.

REACTION FORCE:

\[ R \alpha = \left[ s \sum T_h \alpha_s \bar{x} + s q A_{shi}^2/2 - R_{\alpha}(A_{i\alpha} - A_{i\alpha}) \right] / (A_{i\alpha} - A_{i\alpha}) \]

LOCATION OF ANCHOR STRESS CASE A
\[ A_{i\alpha} < H/4 \quad \sigma_{i\alpha} A_{i\alpha} = 1.68 (A_{i\alpha}^3) / 6 \]
\[ H/4 < A_{i\alpha} < 3 H/4 \quad \sigma_{i\alpha} A_{i\alpha} = 0.05 H^2 (A_{i\alpha} - 4/3) + 0.2 H (A_{i\alpha} - 2 H/3)^2 \]
\[ A_{i\alpha} > 3 H/4 \quad \sigma_{i\alpha} A_{i\alpha} = 0.05 H^2 (A_{i\alpha} - H/2) + 0.2 H (A_{i\alpha} - 2 H/3) + 0.9 H (A_{i\alpha} - 0.75 H)^2 (H - 2 H/3 A_{i\alpha}) \]

STRESS CASE B

\[ A_{i\alpha} < H/4 \quad \sigma_{i\alpha} A_{i\alpha} = 2 K_{as} \bar{A}_{i\alpha} A_{i\alpha}^3 / 3 \]
\[ A_{i\alpha} > H/4 \quad \sigma_{i\alpha} A_{i\alpha} = K_{as} A_{i\alpha}^2 / 8 \quad (4 H - H/2) + K_{as} A_{i\alpha} A_{i\alpha} \quad (A_{i\alpha} - H/4)/2 \]

ZERO SHEAR: \( \Sigma v = 0 \)

CASE A:
\[ v = \Sigma \alpha (0.05 \delta H^2 + 0.4 H (z - H/4)) - s q z = 0 \quad \text{WHERE} \quad z \leq 3 H/4 \]

OR
\[ v = \Sigma \alpha (0.25 \delta H^2 + 0.8 (H - 0.8 z) (z - 0.75 H)) - s q z = 0 \quad \text{WHERE} \quad z > 3 H/4 \]
**ZERO SHEAR - CASE B:**

\[ V = z \cdot R_i - S \left[ K_{\alpha} \gamma H^3 + K_3 \delta H (z - H/4) \right] - S \cdot q \cdot z = \delta \]

**MAX. MOMENT**  
\[ \Sigma M_z = M_{\text{MAX}} \]

**CASE A**  
\[ z \leq 3H/4: \]

\[ \Sigma M_z = \Sigma R_i \cdot (z - A_i) - S \cdot q \cdot z^2/2 - S \cdot \left[ 0.05\gamma H^2 + (z - H/6) + 0.2\delta H^2 (z - H/8) \right] \]

\[ z > 3H/4: \]

\[ \Sigma M_z = \Sigma R_i \cdot (z - A_i) - S \cdot q \cdot z^2/2 - S \cdot \left[ 0.05\gamma H^2 (z - H/6) + 0.2\delta H^2 (z - H/8) + 0.4\delta (z - 0.75H)^2 (H - 2H/3) \right] \]

**CASE B**

\[ \Sigma M_z = \Sigma R_i \cdot (z - A_i) - S \cdot q \cdot z^2/2 - S \cdot \left[ K_{\alpha} \gamma H^3 (z - H/6) + K_3 \delta H (z - H/4)^2/2 \right] \]

**DEPTH OF EMBEDDMENT**

\[ PP = (6C/\phi \gamma + 2C \cdot q) b_i \cdot D \cdot (D/2 + H - A_i) \]

**NEGLIGENCE SOIL PRESSURE**

**CASE A**  
\[ A_i < 3H/4: \]

\[ \Sigma M_{A_i} = M_s + PP - S \cdot \left[ 0.48H \cdot (0.75H - A_i) + 0.05\gamma H^2 (5H/6 - A_i) \right] = 0 \]

\[ A_i > 3H/4: \]

\[ \Sigma M_{A_i} = M_s + PP - S \cdot \left[ 0.88 (H-A_i)^3 / 3 \right] = 0 \]

**CASE B**

\[ \Sigma M_{A_i} = M_s + PP - S \cdot \left[ K_{\alpha} \gamma H \cdot (H - A_i)^2 / 2 \right] = 0 \]

**SOLVE FOR D.**
KIEWIT CRITERIA

STAGE I & II ONLY.

STAGE I

ASSUME PINNED BETWEEN 2-3 FT
BELOW BOTTOM OF CUT &
NEGLECT SOIL RESISTANCE BELOW
BOTTOM OF EXCAVATION.

SANDS: (USE Z FT)

\[ M_{k1} = k_a S \left[ q + \left( \frac{H}{2} + 2 \right) + \frac{g H}{2} \left( \frac{H}{3} + 2 \right) \right] \]

CLAYS:

IF \( z < 0 \) → \( M_{k1} = S \left[ \frac{g H}{2} \left( \frac{H}{3} + 2 \right) + S(q_r - 2c) \right] \)

IF \( z > 0 \) → \( M_{k1} = S \left( \frac{8H + q_e - 2c}{2} \right) \left( \frac{H - z_t}{Z} \right) + S \left( \frac{H - z_t}{Z} + 2 \right) \)

STAGE II

MAX. MOMENT, \( M_{max} = W \frac{L^2}{2} / g \times S

WHERE \( W \) IS THE AVERAGE PRESSURE ON THE SPAN
BELOW THE ANCHOR, AND

\( L \) IS THE LENGTH BETWEEN THE ANCHOR
AND THE BOTTOM OF THE CUT.

SAND:

\[ M_{k2} = S \left[ q_e + q A_1 + (H-A_1) \frac{g}{2} \right] \frac{(H-A_1)^2}{g} \]
KIEFKIT CRITERIA (CONTINUED)

CLAYS

\[ \text{IF } Z_e < 0 \rightarrow MK_2 = S \times [q_e - 2c + 8A_l + 8(H-A_l)/2] (H-A_l)^2/9 \]

\[ \text{IF } Z_e \geq 0 \& Z_e \geq A_l \rightarrow \]

\[ MK_2 = S \times [q_e - 2c + 8H] \times (H - Z_e) \times (Z_e + (H-A_l)) \times (H - A_l)^2/9 \]

\[ \text{IF } Z_e > 0 \& Z_e < A_l \rightarrow \]

\[ MK_2 = S \times [(q_e - 2c + 3A_l) + 8(H-A_l)/2] \times (H - A_l)^2/9 \]

REACTION FORCE IS CALCULATED BY ASSUMING PINNED CONNECTIONS AT TOP AND BOTTOM OF THE CUT.

SANDS:

\[ R_A = K_a S \times [q A_l + 8A_l^2/2] \]

\[ R_B = K_a S \times [H - A_l)^2/4 \times (q_e - 8A_l) + (H - A_l)^3 + 8/6] / (H - A_l) \]

\[ R_K = R_A + R_B \]

CLAYS

\[ \text{IF } Z_e < 0 \rightarrow R_K = S \times [(q_e - 2c) A_l + 8A_l^2/2 + (q_e - 2c + 8A_l) (H - A_l)/2 + 8(H - A_l)^2/6] \]

\[ \text{IF } Z_e \geq 0 \& Z_e > A_l \rightarrow \]

\[ R_K = S \times [(q_e - 2c + 8H) \times (H - Z_e)^2/6] / (H - A_l) \]

\[ \text{IF } Z_e > 0 \& Z_e < A_l \rightarrow \]

\[ R_K = S \times [(q_e - 2c + 8A_l) (A_l - Z_e)/2 + (q_e - 2c + 8A_l) (H - A_l)/2 - 8(H - A_l)^2/6] \]
CONVERT STRIP LOAD PRESSURE TO UNIFORM PRESSURE.

\[ P = 2q * h / \pi * (\theta_2 - \theta_1) \]

WHERE \[ \theta_2 = \tan^{-1} \left( \frac{a+b}{h} \right) \] (RADIANS)

\[ \theta_1 = \tan^{-1} \left( \frac{b}{h} \right) \] (RADIANS)

\[ q_e = \frac{P}{h} \]

\[ : q_e = 2q / \pi * (\theta_2 - \theta_1) \]
WALE ANALYSIS:

ASSUME PINNED, \( M = \omega l^2 / 8 \)

\( \omega l = R_{u} + d / 5 \)

INCREASE \( R_{u} \) BY 33\% TO ACCOUNT FOR PRELOADING TEST.

\( M = 1.33 \times R_{u} + d / 5 + d / 8 \)

\( S_{w} = M / \sigma_{u} \), \( \sigma_{u} = 0.8 \times 36 \text{ ksi} = 28.8 \text{ ksi} \)

\( \therefore S_{w} = 1.33 R_{u} d^2 / 8 \times 28.8 \rightarrow S_{w} = R_{u} d^2 / 14.48 \)

UNBONDED LENGTH:

LAW OF SINES:

\( \frac{L_{u}}{\sin(45 - \phi/2)} = \frac{H - A_{1}}{\sin(45 + \phi/2 + \theta)} \)

\( L_{u} = (H - A_{1}) \times \frac{\sin(45 - \phi/2)}{\sin(45 + \phi/2 + \theta)} \)

REQUIRED CAPACITY OF ANCHOR:

\( P_{e} = R_{e} / \cos \theta \times (d / s) \)
**Bonded Length:**

**Fine to Medium Sand:** \[ L = 10^{\left(\frac{27.3}{14.8} + 9\right)/17.0} \] (Figure C.1)

**Medium - Coarse Sand:** \[ L = 10^{\left(\frac{27.3}{14.8} + 5\right)/13.2} \] (Figure C.2)

**Sandy - Gravel:** \[ L = 10^{\left(\frac{27.3}{14.8} + 9\right)/13.2} \] (Figure C.3)

Depth of overburden 7/13
Diameter ~ 4" - 6"

**Clays:**

<table>
<thead>
<tr>
<th>Clay Consistency</th>
<th>Ult. Anchor Friction (kip/ft²)</th>
<th>Ult. Anchor Capacity (kip/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V. Stiff - Hard</td>
<td>7</td>
<td>11.00</td>
</tr>
<tr>
<td>V. Stiff</td>
<td>6</td>
<td>9.42</td>
</tr>
<tr>
<td>Stiff - V. Stiff</td>
<td>5</td>
<td>7.85</td>
</tr>
<tr>
<td>Stiff</td>
<td>4</td>
<td>6.28</td>
</tr>
<tr>
<td>Med. Stiff</td>
<td>3</td>
<td>4.71</td>
</tr>
<tr>
<td>Medium</td>
<td>2</td>
<td>3.14</td>
</tr>
</tbody>
</table>

Friction Area = \( \pi D \times 1/\text{LF} \)
Assume \( D = 6" = 1/2 \text{ ft} \)
Friction Area = \( \pi /2 \times \text{LF} \)
Ult. Anchor Friction \( \times \pi /2 = \) Ult. Anchor Capacity
Figure C.1
Average Load Capacity of Anchors in Fine to Medium Sands

Figure C.2
Average Load Capacity of Anchors in Medium To Coarse Sands
Figure C.3
Average Load Capacity of Anchors in Sandy Gravel
APPENDIX D
EXAMPLE PROBLEMS
I. WALL PROPERTIES

1. Engineer: D'Amanda
2. Project: Sand Example #1
3. Date: 21 September 1991
4. The elevation of the top of the excavation is 250.00 feet.
5. The elevation of the bottom of the excavation is 215.00 feet.
6. The number of anchors is 3.
   The anchors are located as follows:
<table>
<thead>
<tr>
<th>Anchor</th>
<th>Elevation (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>245.00</td>
</tr>
<tr>
<td>2</td>
<td>235.00</td>
</tr>
<tr>
<td>3</td>
<td>225.00</td>
</tr>
</tbody>
</table>
7. The spacing of the soldier piles is 4.00 feet.

II. SOIL PROPERTIES

8. The elevation of the water table is 0.00 feet.
9. The soil properties are as follow:
<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Elev</th>
<th>Unit Wt</th>
<th>Friction Angle or Cohesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>sand</td>
<td>250.00</td>
<td>0.1100</td>
<td>30.00</td>
</tr>
</tbody>
</table>
10. The slope of the ground behind the wall is 0.00 degrees.
11. The surcharge load is 0.500 ksf.
12. The strip load is 5.00 ksf, 20.00 feet long, and located 50.0 feet from the wall.

III. WALL ANALYSIS RESULTS

13. Estimated width of the soldier pile is 1.00 feet.
14. Factor of safety for passive resistance is 1.0.
15. The wall was excavated 1.0 feet below the proposed anchor location.
16. STAGE ZERO MAXIMUM SECTION EMBEDMENT REACTION(S)
SHEAR MOMENT MODULUS DEPTH
(ft) (k-ft) (in^3) (ft) (kips)
------------------------------------------
1 11.0 57.53 23.97 9.5 ---
2 22.9 59.63 24.84 5.8  R1 = 31.24
  R2 = 43.68
3 20.5 71.43 29.76 5.4  R1 = 53.13
  R2 = 43.68
  R3 = 53.13
4 30.0 73.45 30.60 5.7  R1 = 66.10
  R2 = 51.41
  R3 = 58.76

NOTE: Stage 1 moment based on Kiewit criteria is 43.5 kip-ft.
Stage 2 moment based on Kiewit criteria is 44.2 kip-ft and reaction force is 27.2 kips.

NOTE: Minimum depth of embedment based on maximum moment is 5.7 feet.

NOTE: NYCTA recommends minimum penetration depth of six feet.

IV. ANCHOR AND WALE RESULTS

17. Spacing of the anchors is 8.0 feet.
18. The anchors are set at an angle of 5.0 degrees.
19. The anchors are set in medium to coarse sand.
20. ANCHOR SECTION MODULUS ANCHOR UNBONDED
    ROW OF WALE CAPACITY LENGTH LENGTH
    (in^3) (kips) (ft) (ft)
------------------------------------------
1 73.4 133 13.7 16.6
2 57.1 103 9.4 11.0
3 65.3 118 11.4 5.5

NOTE: Tieback capacity is based on pressure injected anchors using an effective grout pressure in excess of 150 psi with a diameter between 4 to 6 inches and depth of overburden greater than 13 feet.

NOTE: FHWA/RD-82/047 recommends a minimum unbonded length of 15 feet.

END OF ANALYSIS

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SAND PROBLEM #1

- SPACING 4' FT O.C.
- NO GWT
- ESTIMATED WIDTH OF SOLDIER:
  FILE IS 1 FT
- FACTOR OF SAFETY IS PASSIVE RESISTANCE = 1
- OVEREXCAVATE BELOW ANCHOR 1 FT.

STAGE I

\[ K_a = \tan^2(45 - \frac{\theta}{2}) = \tan^2(45 - 30/2) \]
\[ = 1/3 \]

\[ K_p = \tan^2(45 + \frac{\theta}{2}) = \tan^2(45 + 30/2) \]
\[ = 3 \]

STRIP LOAD - CONVERT TO EQUIVALENT SURCHARGE LOAD.

\[ P = 2q/A (\theta - \theta_1) \times H \]

\[ q_e = P/KH = 2q/KH \times (\theta - \theta_1) \rightarrow \theta_2 = \tan^{-1}(50+20/6) = 1.485 \]

\[ \theta_1 = \tan^{-1}(50/6) = 1.451 \]

\[ q_e = 2.5/1 \times (1.485-1.451)/3 \]

\[ q_e = 0.324 \text{ KSF} \quad \text{ADD SURCHARGE LOAD} + 0.5 \text{ KSF} \]

\[ q_e = 0.824 \text{ KSF} \]

\[ \text{Force - Soil} \quad P_a = K_0 \theta H^{3/2} \times S = \frac{1}{3} \times 0.11 \times 6^{3/2} \times 6 = 2.64 \text{ K} \]

\[ \text{Force - Surcharge} \quad P_q = K_0 q_e H \times S = \frac{1}{3} \times 0.824 \times 6 \times 6 = 6.592 \text{ K} \]

\[ P_{t } \text{ OF ZERO SHEAR} \]

\[ \Sigma V = 0 = P_a + P_a + K_0 (3H+q_e)dz - (3K_p fs - K_0)bfS \times 2/2 \]

\[ = 2.64 + 6.592 + \frac{1}{6}(0.11 \times 6 + 0.824)(2) - (3 \times 3 - 5)(0.11)(1) \times 2/2 \]

\[ z = 4.95' + 6 = 10.95 \text{ FT} \quad (\text{USE } Z = 5') \]

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MAX. MOMENT

\[ \Sigma M = P_0 (H/3 + \ell) + P_0 (H/2 + \ell) + K_0 (8H + q_0) df E^2/2 - (3K_p/K_s - K_0) b y E^2/6 \]

\[ = 2.64 (6/3 + 5) + 6.572 (6/2 + 5) + 0.435 (5) 1/2 - 0.477 5^{3/2} \]

\[ = 57.53 \text{ k-ft} \]

DEPTH OF EMBEDDIMENT

\[ \Sigma M_0 = 0 = P_0 (H/3 + D) + P_0 (H/2 + D) + K_0 (8H + q_0) df E^2/2 - (3K_p/K_s - K_0) b y D^{3/6} \]

\[ = 2.64 (2 + D) + 6.592 (3 + D) + 0.495 D^{1/2} - 0.477 D^{3/3} \]

\[ D = 9.46 \text{ ft} \]

STAGE II

STRIP LOAD:

\[ \theta_2 = 1.316 \text{ & } \theta_1 = 1.261 \]

\[ q_e = 10/4 (1.346 - 1.261)/13 + q \]

\[ q_e = 0.812 \text{ ksf} + 0.5 = 1.312 \text{ ksf} \]

PY OF ZERO FORCES ON EMBEDDED PILE

\[ P_0 = \frac{1}{2} \times 0.11 \times 16^2 \times 4 = 18.773 \text{ k} \]

\[ P_0 = \frac{1}{2} \times 1.312 \times 16 \times 4 = 27.989 \text{ k} \]

\[ pp = (3K_p/K_s) df \gamma = (3 \times 3 - \gamma) \times 1 \times 0.11 \]

\[ = 0.953 \text{ ksf} \]

\[ \Sigma F_y = P_0 + P_0 + K_0 (8H + q_0) df \gamma - pp E^{2/2} = \phi \]

\[ = 18.773 + 27.989 + K_0 (1.312 + 16 \times 0.11) K - 0.953 E^{2/2} \]

\[ K = 11.04 \text{ k-ft} \]

Say \( K = 11 \times \]

121
**REACTION FORCE**

Assume hinged at \( x \) (zero moment)

\[
\Sigma M_x = 0 = P_3 (H/3 + x) + P_q (H/2 + x) + L_3 (8H_1 + q_0) b_1 x^{3/2} - P P x^{3/6} - (H - A_1 + Z) R_1
\]

\[
= 18.733 (16/3 + 11) + 27.989 (16/2 + 11) + 1.024 (11)^{3/2} - 0.477 (11)^{3/3} - (16 - 5 + 11) R_1 = 0
\]

\[
R_1 = 31.27 \text{ kN}
\]

**ZERO SHEAR**

\[
\Sigma V = 18.733 + 27.989 + 1.024 x - 0.477 x^2 - 31.27 x = 6.9 \text{ kN} + 16 = 22.9 \text{ kN}
\]

**MAX. MOMENT**

\[
\Sigma M_z = 18.733 (16/3 + 6.9) + 27.989 (16/2 + 6.9) + 1.024 (6.9)^{3/2} - 0.477 (6.9)^{3/3} - 31.27 (11 + 6.9)
\]

\[
= 58.61 \text{ kN} \cdot \text{m}
\]

**SECTION MODULUS, \( S = \frac{M_{max}}{2.4 = 58.61/2.4} \]

\[
= 24.92 \text{ in}^3
\]

**DEPTH OF EMBEDMENT**

\[
\Sigma M_{y_0} = 58.61 + 0.477 D^2 (11 + 2/3 D) - \left( \frac{1}{3} (1.312 + 5 \times 0.11) \times 4/2 \right) \times x^2
\]

\[
- 4 (\frac{x}{2}) (0.11) x^{3/3} - \frac{1}{3} (1.312 + 6 \times 0.11) \times D (D/2 + 11) = 0
\]

\[
D = 5.8 \text{ ft}
\]
**Stage III**

**Strip Load** → $\theta_2 = 1.215$ & $\theta_1 = 1.091$

$q_e = 10/\pi (1.215 \cdot 1.091)/3 + 0.5$

$q_e = 1.682$ ksf

$T_{soil} = 0.65 \times 2.5 \times s = 0.65(\frac{2}{3})(0.11) \times 2.5 \times 4$

$= 2.478$

$T_h = T_{soil} + T_q = 2.478 + 1.682 \times \frac{2}{3} \times 4 = 4.72$ ksf

**Reactions**

$\Sigma M_{R_2} = T_h \times A_2/2 - R_1 \times (A_2 - A_1) = 0$

$= 4.72 \times 15/2 - 10R_1 \rightarrow R_1 = 53.11$ k

$\Sigma M_{base} = T_h \times H^2/2 - R_1 \times (H - A_1) - R_2 \times (H - A_2)$

$= 4.72 \times 26^2/2 - 53.11 \times 21 - 11R_2 = 0$

$R_2 = 43.64$ k

**Zero Shear**

$\Sigma V = 0 = 53.11 + 43.64 - 4.72 \times z$

$z = 20.5$ ft

**Max Moment**

$\Sigma M_z = 53.11(20.5 - 5) + 43.64(20.5 - 15) - 4.72 \times 20.5^2/2$

$= 71.435$ k-ft

$S = M_{max}/2.4 = 71.435/2.4$

$= 29.76$ in

123
EMBEDMENT DEPTH

\[ \Sigma M_2 = 71.435 + 3 \times 3 \times 0.11D^2/2 (2/3D + 1) - 4.72 \times 11^{1/2} \]
\[ D = 5.43 \text{ ft} \]

STAGE IV

STRIP LOAD:
\[ \theta_2 = 1.107 \quad \text{and} \quad \theta_1 = 0.960 \]
\( q_{strip} = 194 + (1.107 - 0.960)/1 = 1.904 \text{ ksf} \)
\[ q_e = 1.904 + 0.5 = 1.904 \text{ ksf} \]
\[ q_{soil} = 0.65 (1/3) (0.11) (35) + 4 = 3.337 \text{ ksf} \]
\[ q_h = 3.337 + 1.904/3 \times 4 = 5.875 \text{ ksf} \]

REACTION FORCES

\[ \Sigma M_2 = 5.875 \times 15^{3/2} - 10R_1 = 0 \]
\[ R_1 = 66.09 \text{ k} \]
\[ \Sigma M_3 = 5.875 \times 25^{3/2} - 20 \times 66.09 - 10R_2 = 0 \]
\[ R_2 = 51.41 \text{ k} \]
\[ \Sigma M_{base} = 5.875 \times 35^{3/2} - 30 \times 66.09 - 20 \times 51.41 - 10R_3 = 0 \]
\[ R_3 = 58.75 \text{ k} \]

ZERO SHEAR

\[ \Sigma V = 0 = 66.09 + 51.41 + 58.75 - 5.875 Z \]
\[ Z = 30 \text{ ft} \]

MAX MOMENT

\[ \Sigma M_2 = 66.09 \times 25 + 51.41 \times 15 + 58.75 \times 5 - 5.875 \times 30^{3/2} \]
\[ M_{max} = 73.9 \text{ k ft} \]
\[ S = 30.58 \text{ k ft}^3 \]
EMBEDMENT DEPTH

\[ EM_{3} = 73.41 + 9(0.11)D^{2}/2(3/3D + 10) - 5.875(10)^{2}/2 = 8 \]
\[ D^{2}(3/3D + 10) - 945.15 = 0 \rightarrow D = 5.68 \text{ ft} \]

BASED ON \( M_{\text{MAX FOR THE 4 STAGES}} > D_{\text{MIN}} = 5.68 \text{ ft} \)

BUT USE \( D = 6 \text{ ft} \)

**KREVIT CRITERIA**

**STAGE I -**

\[ M_{\text{MAX}} = 2.64 \times (6/3 + 2) \times 6.592(6/2 + 2) \]
\[ = 43.5 \text{ k-ft} \]

**STAGE II -**

\[ M_{\text{MAX}} = \omega L^{2}/9 \]
\[ \omega = \left[ (1/3 \times 0.11 \times 5 + 1.312/3) \times 4/11 + 4/3 \times 0.11(11/2) \right] / 11 \]
\[ = 3.289 \text{ k-ft} \]

\[ M_{\text{MAX}} = 3.289 \times 11^{2}/9 = 44.22 \text{ k-ft} \]

\[ R_{k} = \left[ (K_{k} \times 0.11 \times 5/2 + 1.312/3 \times 5) + (27.3 \times 1/2 + 9/3(0.11)(11^{3}/6)) / 11 \right] \]
\[ = 27.18 \text{ kV} \]

**WALE DESIGN**

**USE ANCHOR SPACING = 8' & PILE SPACING = 4'**

**MAX ANCHOR FORCES,**  Row 1 \( \rightarrow 66.10 \text{ k} \)
\n" " " " " "  Row 2 \( \rightarrow 51.91 \text{ k} \)
\n" " " " " "  Row 3 \( \rightarrow 58.76 \text{ k} \)

**SECTION MODULUS,**  \( S_{w1} = R_{d} d^{3}/4.48 \)

Row 1:  \( S_{w1} = 66.1 \times 8^{3}/14.4 \times 4 = 73.4 \text{ in}^{3} \)
Row 2:  \( S_{w2} = 51.9 \times 8^{3}/14.4 \times 4 = 57.12 \text{ in}^{3} \)
Row 3:  \( S_{w3} = 58.76 \times 8^{3}/14.4 \times 4 = 65.29 \text{ in}^{3} \)
**ANCHORS**

<table>
<thead>
<tr>
<th>Row</th>
<th>Req'd Capacity</th>
<th>Bonded Length</th>
<th>Unbonded Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>132.7 k</td>
<td>13.7 ft</td>
<td>16.5 ft</td>
</tr>
<tr>
<td>2</td>
<td>103.2 k</td>
<td>9.4 ft</td>
<td>11.0 ft</td>
</tr>
<tr>
<td>3</td>
<td>118.0 k</td>
<td>11.4 ft</td>
<td>15.5 ft</td>
</tr>
</tbody>
</table>

**CAPACITY = \( R_i \times \frac{(1/5)}{\cos \theta} \)**

Use \( \theta = 5^\circ \)

**CAPACITY = \( R_i \times \frac{(8/4)}{\cos 5^\circ} = 2.0076 \, R_i \)**

Row 1 \( \rightarrow \) CAPACITY \( (U_1) = 2.0076 \times 66.1 = 132.7 \, k \)

**ASSUME MEDIUM TO COARSE SAND**

**Bonded Length, \( L = 10 \, (U + 74.5)/132.9 \)**

\( L_1 = 10 \times \frac{(132.7 + 74.9)}{132.9} = 13.7 \, \text{ft} \)

**Unbonded Length, \( L_u = (U - A) \times \frac{\sin(45^\circ - \frac{\pi}{4})}{\sin(45^\circ - \frac{\pi}{2} + \theta)} \)**

\( L_{u1} = (135 - 5) \times \frac{\sin(45 - 30/2)}{\sin(45 + 30/2 + 5)} = 16.55 \, \text{ft} \)

**Lagging Size \( \rightarrow \) USE 3" x 12" FROM FHWA-RD-75-128 (1976).**
I. WALL PROPERTIES

1. Engineer: D'Amanda
2. Project: Sand Example #2
3. Date: 21 September 1991
4. The elevation of the top of the excavation is 10.00 feet.
5. The elevation of the bottom of the excavation is -10.00 feet.
6. The number of anchors is 2.
   The anchors are located as follows:
   Anchor | Elevation (feet)
   -------|-----------------|
       1  |      5.00
       2  |     -5.00

7. The spacing of the soldier piles is 4.00 feet.

II. SOIL PROPERTIES

8. The elevation of the water table is 0.00 feet.
9. The soil properties are as follow:

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Elev</th>
<th>Unit Wt</th>
<th>Friction Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>sand</td>
<td>10.00</td>
<td>0.1100</td>
<td>30.00</td>
</tr>
<tr>
<td>sand</td>
<td>3.00</td>
<td>0.1150</td>
<td>35.00</td>
</tr>
<tr>
<td>sand</td>
<td>-4.00</td>
<td>0.1180</td>
<td>38.00</td>
</tr>
</tbody>
</table>

10. The slope of the ground behind the wall is 12.50 degrees.
11. The surcharge load is 0.000 ksf.
12. The strip load is 0.00 ksf, 0.00 feet long, and located 0.0 feet from the wall.

III. WALL ANALYSIS RESULTS

13. Estimated width of the soldier pile is 1.00 feet.
14. Factor of safety for passive resistance is 1.0.
15. The wall was excavated 1.0 feet below the proposed anchor location.
16. STAGE ZERO MAXIMUM SECTION EMBEDMENT REACTION(S)

<table>
<thead>
<tr>
<th>SHEAR MOMENT</th>
<th>MODULUS</th>
<th>DEPTH</th>
<th>(ft)</th>
<th>(k-ft)</th>
<th>(in^3)</th>
<th>(ft)</th>
<th>(kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.9</td>
<td>32.85</td>
<td>13.69</td>
<td>9.7</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>23.6</td>
<td>43.25</td>
<td>18.02</td>
<td>6.6</td>
<td>R1 = 23.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>17.5</td>
<td>12.32</td>
<td>5.14</td>
<td>3.8</td>
<td>R1 = 44.37</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTE: Stage 1 moment based on Kiewit criteria is 25.2 kip-ft.
Stage 2 moment based on Kiewit criteria is 44.3 kip-ft and reaction force is 18.9 kips.

NOTE: Minimum depth of embedment based on maximum moment is 1.7 feet.

NOTE: NYCTA recommends minimum penetration depth of six feet.

IV. ANCHOR AND WALE RESULTS

17. Spacing of the anchors is 9.0 feet.
18. The anchors are set at an angle of 10.0 degrees.
19. The anchors are set in fine to medium sand.
20.

<table>
<thead>
<tr>
<th>ANCHOR ROW</th>
<th>SECTION MODULUS OF WALE (in^3)</th>
<th>ANCHOR CAPACITY (kips)</th>
<th>ANCHOR LENGTH (ft)</th>
<th>UNBONDED LENGTH (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27.7</td>
<td>45</td>
<td>6.0</td>
<td>7.4</td>
</tr>
<tr>
<td>2</td>
<td>15.4</td>
<td>25</td>
<td>4.4</td>
<td>2.5</td>
</tr>
</tbody>
</table>

NOTE: Tieback capacity is based on pressure injected anchors using an effective grout pressure in excess of 150 psi with a diameter between 4 to 6 inches and depth of overburden greater than 13 feet.

NOTE: FHWA/RD-82/047 recommends a minimum unbonded length of 15 feet.

END OF ANALYSIS
**SAND EXAMPLE 2**

**SLOPE BACKFILL:**

\[
K_a = \frac{\cos^2 \phi}{\cos(4\phi/3)\left[1 + \frac{\sin\phi - \sin(\pi/3)}{\cos(\pi/3) \cos \phi}\right]^2}
\]

\[\beta = 12.5^\circ\]

**STAGE I:**

\[\alpha_c = 110 \text{pcf} = 0.110 \text{kcf}\]

\[\phi_c = 30^\circ\]

\[V_b = 0.110 \text{kcf} \quad \phi_b = 30^\circ\]

\[K_a = 0.354\]

\[K_{P_b} = T \tan^2(\pi/2) = 3 \quad K_{\phi_b} = 1/3\]

**PT of ZERO SHEAR:**

\[P_s = K_a \delta H^2/2 \times S = 0.354(11)(6)^2/2 \times 9\]

\[= 6.31 \text{ Kips}\]

**ASSUME FS = 1 & b = 1**

\[\Sigma V = 0 = P_s + K_a(\delta H)bf \times z - (K_P/FS - K_{\phi}) \delta bf \times z^3/6\]

\[+ (K_P/FS - K_{\phi}) \gamma_w bf (z-1)^2/2\]

\[= 6.31 + 0.42(1.1 \times 6) \times 1 \times z - (9 - 3)(11 \times 1) \times z^3/2 +\]

\[(9 - 3)(0.0624 \times 9 - 1)^2/2\]

\[= 6.31 + 0.22z - 0.47z^2 + 0.27(9 - 1)^2 = 0\]

\[z = 4.9 \text{ ft} \quad + h = 10.9 \text{ ft.}\]

**Max. Moment; M_max = \Sigma M_z**

\[\Sigma M_z = P_s \times (H/3 + z) + K_a(\delta H)bf \times z^2/2 - (3K_P/FS - K_{\phi}) \delta bf \times z^3/6\]

\[+ (3K_P/FS - K_{\phi}) \gamma_w bf (z-1)^3/6\]
\[ \Sigma M_e = 6.31 \left( \frac{6}{3} + 4.9 \right) + \frac{1}{3} \left( \frac{11 \times 6}{3} \right) \times 4.9^2 \frac{L}{2} - \left( 3 \times 3 - \frac{1}{3} \right) \left( \frac{11}{11} \right) \times 4.9^3 / 6 \]

\[ M_{\text{max}} = 32.83 \text{ k. ft} \]

\[ S = \frac{M_{\text{max}}}{2.4} = 13.63 \text{ in}^3 \]

**Embedment Depth:** \[ \Sigma M_d = 0 \]

\[ \Sigma M_d = 6.31 (2 + D) + \frac{1}{3} \left( \frac{11 \times 6}{3} \right) - D^3 / 2 - (1 - \frac{1}{3}) \left( \frac{11}{11} \right) D^3 / 6 + (9 - \frac{1}{3}) 0.0624 (D - \frac{1}{3}) = 0 \]

\[ D = 9.6 \text{ ft} \]

**Stage II:**

\[ \gamma_{\text{ave}} = [7 \times 0.11 + 7 \times 0.115 + 2 \times 0.118] / 16 \]

\[ = 0.1132 \text{ kcf} \]

\[ \phi_{\text{ave}} = 33.2^\circ \]

\[ \sigma_b = 0.118 \text{ & } \phi_b = 38^\circ \]

\[ K_a = 0.3078 \]

\[ K_p = 4.204 \text{ & } K_a = 0.239 \]

**Determine PT where Net Forces on Embedded Pile & Assume Hinged:**

\[ P_z = K_a \delta H x / 2 * S = 0.3078 \times 0.1132 \times 16^{3/2} \times 9 \]

\[ = 40.14 \text{ k} \]

\[ (3K_p / fs - K_a) b_s (\gamma - \delta_w) = P_p = (3 \times 4.204 - 0.239) \times 1 \times (0.118 - 0.0624) \]

\[ P_p = 0.688 \text{ k/ft} \]

\[ \Sigma F_y = P_z + K_a \delta H x - P_p * x^{3/2} \]

\[ = 40.14 + 0.239 \times 0.1132 \times 16 - 0.688 x^{3/2} \]

\[ = 40.14 + 0.433 x - 0.394 x^2 \rightarrow x = 11.5 \text{ ft} \]
**REACTION FORCE (ASSUME HINGED AT X, ZERO MOMENT).**

\[ \Sigma M_x = P_s \cdot (h/3 + x) + K_{2b} \delta H x^2/2 - P \cdot x^3/6 - R_1(11 + x) = 0 \]
\[ = 40.14(16/3 + 11.5) + 0.43(11.5/2) - 0.62(11.5)^3/6 - R_1(11 + 11.5) = 0 \]
\[ = 530 - 22.5 R_1 = 0 \rightarrow R_1 = 23.55 \text{ KIPS} \]

**ZERO SHEAR**

\[ \Sigma V = 0 = P_s + K_{2b} \delta H z - P \cdot z^2/2 - R_1 = 0 \]
\[ = 40.14 + 0.433 z^2 - 0.34 z^2 - 23.55 = 0 \]
\[ = 16.64 + 0.433 z^2 - 0.344 z^2 \rightarrow \begin{array}{c} z = 7.6 \text{ ft} + 16 = 23.6 \end{array} \]

**MAX MOMENT**

\[ \Sigma M_z = P_s \cdot (h/3 + z) + K_{2b} \delta H z^2/2 - P \cdot z^3/6 - R_1(11 + z) \]
\[ = 40.14(16/3 + 7.6) + 0.433(7.6)^2/2 - 0.62(7.6)^3/6 - 23.55(11 + 7.6) \]
\[ M_{\text{max}} = 43.80 \text{ K-ft} \]
\[ S = M_{\text{max}}/24 = 18.25 \text{ in}^3 \]

**EMBEDMENT DEPTH**

\[ \Sigma M_{AI} = M_{\text{max}} + P \cdot D^3/2 \cdot (2D/3 + 11) \]
\[ - K_{2b} \delta A_1 \cdot 1/2 \cdot 5^2 - K_{2b} \delta A_1 \cdot (32/11)^2 \cdot 6 \]
\[ - K_{2b} \delta H D (2D/2 + 11) = 0 \]
\[ = 43.8 + 0.344 D^2 (2D/3 + 11) - 0.3078 \cdot 0.1132 \cdot 5 \cdot 11^3/2 \cdot 9 \]
\[ - 0.3078 (0.1132) 11^3/2 \cdot 6 - 0.239(0.1132)(16 D)(D/2 + 11) = 0 \]
\[ = -190.2 + 0.344 D^2 (2D/3 + 11) - 0.433 D (D/2 + 11) \]
\[ D = 6.6 \text{ ft} \]

\[ \begin{align*} \text{Max} & \quad A_1 = 5 \end{align*} \]
STAGE III:

\[ \delta_{\text{ave}} = \frac{7 \times 0.11 + 7 \times 0.115 + 6 \times 0.118}{20} \]

\[ = 0.119 \text{ kcf} \]

\[ \phi_{\text{ave}} = 34.15^\circ \]

\[ \delta_b = 118 \text{ kcf} \& \phi_b = 38^\circ \]

\[ K_a = 0.2953 \]

\[ K_p = 4.204 \]

\[ \sigma_{\text{soil}} = 0.65 K_a \theta H = 0.65 \times (0.2953) (0.114) (20) \times 9 \]

\[ = 3.94 \text{ kcf} \]

**Reaction Forces**

\[ R_1 = \sigma_s \times A_1^2 / 2 (A_2 - A_1) = 3.94 \times 15^2 / 2 (15 - 5) \]

\[ R_1 = 44.33 \text{ kN} \]

\[ R_2 = [\sigma_s (h^2/2 - R_1 (h - A_1)) / (h - A_2)] \]

\[ = [3.94 \times 20^2 / 2 - 44.33 \times (20 - 5)] / (20 - 5) \]

\[ R_2 = 24.61 \text{ kN} \]

**Zero Shear**

\[ \Sigma V = 0 = R_1 + R_2 - \sigma_s \times Z \]

\[ Z = (44.33 + 24.61) / 3.94 \rightarrow Z = 17.5^\circ \]

**Max Moment** \( \Sigma M_z \)

\[ \Sigma M_z = R_1 (A_2 - A_1) + R_2 (Z - A_2) - \sigma_s Z^2 / 2 \]

\[ = 44.33 (17.5 - 5) + 24.61 (17.5 - 15) - 3.94 \times 17.5^2 / 2 \]

\[ M_{\text{max}} = 12.34 \text{ k-ft} \]

\[ S = M_{\text{max}} / 2.4 = 5.14 \text{ in}^3 \]

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**EMBEDMENT DEPTH**

\[ \Sigma M_{a2} = M_s + 3K_s \Phi_s (4.54)4D^{3/2} \left( \frac{2D}{3} + 5 \right) - \phi \left( S \frac{5}{2} \right) = \Phi \]

\[ = 12.39 + (3 \times 4.201 \times 0.058)D^{3/2} \left( \frac{2D}{3} + 5 \right) - 3.99 \left( S \frac{5}{2} \right) \]

\[ = -36.91 + 0.3506D^{3/2} \left( \frac{2D}{3} + 5 \right) = 0 \]

\[ D = 3.75 \text{ FT} \]

\[ D_{MIN} \rightarrow USE M_s = 43.8 \]

\[ \Sigma M_{a2} = -5.95 + 0.3506D^{3/2} \left( \frac{2D}{3} + 5 \right) = 0 \]

\[ D_{av} = 1.6 \text{ FT} \]

**CANTILEVER ANALYSIS (NOT INCLUDED IN PROGRAM)**

**STAGE 1**

\[ M_{max} = SK \Phi \frac{l^3}{6} = 9 \times 0.354 \times 0.110 \times 6^{3/6} \]

\[ = 12.62 \text{ K FT} \]

**STAGE 2**

\[ P = \frac{K \Phi S}{40} \times \left( x^5 - 5x^4 x + 4x^5 \right) \left( l - x \right)^3 \]

\[ = 0.3078 \times 0.1132 \times \frac{9}{40} \times \left( 5^5 - 5(16)^4 + 4 \times 16^3 \right) \left( 16 - 5 \right)^3 \]

\[ P = 15.07 \text{ K} \]

\[ M_{max} = SK \Phi \frac{l^3}{6} - P (l - x) \]

\[ = 9 \times 0.3078 \times 0.1132 \times 16^{3/6} - 15.07 (16 - 5) \]

\[ M_{max} = 48.30 \text{ K} \]

**KIEWIT ANALYSIS**

**STAGE 1**

\[ M_{k1} = K_a \Phi H^{3/2} S \left( H / 3 + 2 \right) = 0.354 \times 11 \times 6^{3/2} \times 9 \times (6/3 + 2) \]

\[ = 25.2 \text{ K FT} \]
**STAGE 2**

\[ M_k = k_0 S (H-A_i)^2 \times \frac{8}{2} (H+A_i)/g \]

\[ = 0.3078 \times g (11)^2 \times \frac{0.1132}{2} (16+5)/g \]

\[ M_k = 44.27 \text{ kN/m} \]

\[ R_k = k_0 S A_i^2/2 + \left[ k_0 S (H-A_i)^2 (3A_i) + (H-A_i)^3 k_0 S / 6 \right]/(H-A_i) \]

\[ = 0.3078 + 0.1132 \times g (11)^2/2 + \]
\[ \left[ 0.3078 \times 9 (11)^2 (0.1132+5) + (113) (0.3078) (0.1132)/6 \right]/11 \]

\[ R_k = 18.87 \text{ kN/m} \]

**ANCHORS**

\[ R_1 = 44.33 \text{ kN/m} \]

\[ R_2 = 24.61 \text{ kN/m} \]

**Spacing of Anchors** → d = 8 ft

**Inclination Angle** → θ = 10°

**Anchor Capacity for Top Row**, \( U_1 = \frac{44.33 \times (9/3) \cos 10°}{30/1} \)

\[ U_1 = 45.0 \text{ kN/m} \]

**Anchor Capacity for Bottom Row**, \( U_2 = 24.6 \times (9/3) \cos 10° \)

\[ U_2 = 25.0 \text{ kN/m} \]

**Bonded Length**:

Assume Fine to Medium Sand: \( \gamma = 0.1 \times (5 + \tan 30°) \)

\[ L_{A_1} = 10 \text{ ft} \]

\[ L_{A_2} = 10 \text{ ft} \]

**Unbonded Length**: \( L_u = (H-A_i) \times \frac{\sin (45-6/2)}{\sin (45+6/2+\theta)} \)

\[ L_{u_1} = (20-5) \times \sin (45-34.15/2) / \sin \left(45 + 34.15/2 + 10\right) \]

\[ L_{u_1} = 7.4 \text{ ft} \]
\[ L_{u2} = \frac{(20-15) \sin(45-34.15/2)}{\sin(45+34.15/2+10)} \]
\[ L_{u2} = 2.46 \text{ ft} \]

**Wale Section Modulus:**

\[ S_w = Ra d^2/14.4 \]

\[ \frac{S_w_1}{S_w_2} = 44.33 \times 9^2/14.4 \times 9 \]
\[ S_w_1 = 27.7 \text{ in}^3 \]

\[ \frac{S_w_2}{S_w_2} = 24.61 \times 9^2/14.4 \times 9 \]
\[ S_w_2 = 15.4 \text{ in}^3 \]

\[ \therefore \quad EDA \]
I. WALL PROPERTIES

1. Engineer: D'Amanda
2. Project: Clay Example #1
3. Date: 21 September 1991
4. The elevation of the top of the excavation is 100.00 feet.
5. The elevation of the bottom of the excavation is 60.00 feet.
6. The number of anchors is 3.
   The anchors are located as follows:
<table>
<thead>
<tr>
<th>Anchor</th>
<th>Elevation (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>90.00</td>
</tr>
<tr>
<td>2</td>
<td>80.00</td>
</tr>
<tr>
<td>3</td>
<td>70.00</td>
</tr>
</tbody>
</table>
7. The spacing of the soldier piles is 5.00 feet.

II. SOIL PROPERTIES

8. The elevation of the water table is 0.00 feet.
9. The soil properties are as follow:
<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Elev</th>
<th>Unit Wt</th>
<th>Friction Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>clay</td>
<td>100.00</td>
<td>0.1100</td>
<td>0.50</td>
</tr>
<tr>
<td>clay</td>
<td>85.00</td>
<td>0.1200</td>
<td>1.75</td>
</tr>
</tbody>
</table>
10. The slope of the ground behind the wall is 0 degrees.
11. The surcharge load is 0.750 ksf.
12. The strip load is 5.00 ksf, 10.00 feet long, and located 50.0 feet from the wall.

III. WALL ANALYSIS RESULTS

13. Estimated width of the soldier pile is 1.00 feet.
14. Factor of safety for passive resistance is 1.0.
15. The wall was excavated 1.0 feet below the proposed anchor location.
16. STAGE ZERO MAXIMUM SECTION EMBEDMENT REACTION(S)

<table>
<thead>
<tr>
<th>SHEAR MOMENT</th>
<th>SECTION EMBEDMENT</th>
<th>REACTION(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(ft)</td>
<td>MODULUS</td>
<td>(in^3)</td>
</tr>
<tr>
<td>1</td>
<td>13.6</td>
<td>119.25</td>
</tr>
<tr>
<td>2</td>
<td>24.3</td>
<td>91.14</td>
</tr>
<tr>
<td>3</td>
<td>25.1</td>
<td>150.38</td>
</tr>
<tr>
<td>4</td>
<td>34.7</td>
<td>123.01</td>
</tr>
</tbody>
</table>

NOTE: Stage 1 moment based on Kiewit criteria is 137.1 kip-ft.
Stage 2 moment based on Kiewit criteria is 65.8 kip-ft and reaction force is 29.1 kips.

NOTE: Minimum depth of embedment based on maximum moment is 1.9 feet.

NOTE: NYCTA recommends minimum penetration depth of six feet.

NOTE: A total stress analysis approach was used.

IV. ANCHOR AND WALE RESULTS

17. Spacing of the anchors is 5.0 feet.
18. The anchors are set at an angle of 7.5 degrees.
19. The anchors are set in stiff to very stiff clay.
20. ANCHOR SECTION MODULUS ANCHOR ANCHOR UNBONDED
    UNBONDED
    ROW OF WALE CAPACITY LENGTH LENGTH
    (in^3) (kips) (ft) (ft)
| 1 | 73.3 | 213 | 27.1 | 25.7 |
| 2 | 35.8 | 104 | 13.3 | 17.8 |
| 3 | 44.7 | 130 | 16.5 | 8.9 |

NOTE: Tieback capacity is based on post-grouted anchors using an effective grout pressure in excess of 150 psi with a diameter of six inches.

NOTE: FHWA/RD-82/047 recommends a minimum unbonded length of 15 feet.

END OF ANALYSIS

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CLAY EXAMPLE W/O WTR TABLE

STAGE I

CUT: \( y = 110 \) & \( c = 0.5 \text{kpsf} \)
BASE: \( C_{ave} = \frac{4 \times 0.5 + 16 \times 1.75}{2} = 1.5 \text{kpsf} \)

EQUIVALENT \( q \) FOR STRIP LOAD:

\[
\begin{align*}
\theta_2 &= \tan^{-1} \left( \frac{a + b}{h} \right) \\
&= \tan^{-1} \left( \frac{10 + 50}{11} \right) = 1.389 \\
\theta_1 &= \tan^{-1} \left( \frac{b}{h} \right) \\
&= \tan^{-1} \left( \frac{50}{11} \right) = 1.354 \\
q_e &= \frac{p}{h} = 2q \frac{h}{\pi} \times (\theta_2 - \theta_1) / h \\
&= 2 \times 5 \frac{ft}{\pi} \times (1.389 - 1.354) \\
q_e &= 0.112 \text{kpsf}
\end{align*}
\]

TENSION ZONE:

\[
\begin{align*}
\zeta &= (2c - q) / \delta \\
\zeta &= (2 \times 0.5 - (0.75 + 0.112)) / 0.11 \\
&= 1.25 \text{ ft}
\end{align*}
\]

STRESSES:

\[
\begin{align*}
\sigma_s &= \left[ \delta h + q - 2c \right] \times 5 \\
&= \left[ 0.11 + 11 + (0.75 + 0.112) - 2 \times 0.5 \right] \times 5 \\
&= 5.375 \text{kpsf}
\end{align*}
\]

\[
\begin{align*}
PP &= (2c_b \times 3 - (\delta h + q - 2c)) \times b_f \\
&= (8c_b - \delta h - q) \times b_f \\
&= [(8 \times 1.5 - 0.11 + 11 - (0.75 + 0.11))] \times 1 \\
PP &= 9.93 \text{kpsf}
\end{align*}
\]
PT OF ZERO SHEAR:

\[ \Sigma V = 0 = \sigma_s (h - z_t)/2 - pp \times z \]

\[ z = 5.375 \times (11 - 1.25)/2 / 9.93 \]

\[ z = 2.61 + \frac{1}{11} (h) = 13.6 \text{ ft} \]

**Max Moment:** \( \Sigma M_z = M_{\text{max}} \)

\[ \Sigma M_z = \sigma_s (h - z_t)/2 \times ((h - z_t)/3 + z) - pp \times z^2/2 \]

\[ = 5.375 \times (11 - 1.25)/2 \times ((11 - 1.25)/3 + 2.6) - 9.93 \times 2.6^2/2 \]

\[ = 119.72 \text{ k ft} \]

\[ S = M/2.4 = 119.72/2.4 = 49.89 \text{ in}^3 \]

**Depth of Embedment**

\[ \Sigma M_D = 0 = \sigma_s (h - z_t)/2 \times [(h - z_t)/3 + D] - pp \times D^2/2 \]

\[ = 5.375 \times (11 - 1.25)/2 \times [(11 - 1.25)/3 + D] - 9.93 \times D^2/2 \]

\[ = 26.20 \times (3.25 + D) - 9.965D^2 = 0 \]

\[ \therefore D = 7.55 \text{ ft} \]

**Stage II:**

**Cut:** \( \delta_{\text{ave}} = (15 \times 11 + 6 \times 12)/21 \)

\[ = 0.1129 \text{ ksf} \]

\( c_{\text{ave}} = (15 \times 0.5 + 6 \times 1.75)/21 \)

\[ = 0.857 \text{ ksf} \]

**Base:** \( c = 1.75 \text{ ksf} \)

**Ge Strip:**

\[ \theta_2 = \tan^{-1}(60/21) = 1.239 \]

\[ \theta_1 = \tan^{-1}(50/21) = 1.173 \]

\[ q_2 = 10 \times \delta_2 \times (1.239 - 1.173) = 0.194 \text{ ksf} \]
TENSION ZONE:

\[ Ze = \frac{(2 \times 0.857 - (0.75 + 0.134))}{0.1129} \]
\[ = 6.82 \text{ ft} \quad \text{or} \quad Ze \text{ stage } Z = 1.25 \text{ ft} \]

Use \( Ze = 1.25 \text{ ft} \)

FIND PT OF NET ZERO FORCES IN EMBEDDED PIPE

\[ J_S = (0.1129 \times 2.1 + 0.75 + 0.134 - 2 \times 0.857) \times 5 \]
\[ = 8.005 \text{ ksf} \]

\[ pp = (8 \times 1.75 - 0.1152 \times 21 - (0.75 + 0.194)) \times 1 \]
\[ = 10.64 \text{ ksf} \]

\[ \Sigma F_x = 0 = J_S \left( h - Z_p \right) / 2 - pp \times x \]
\[ x = 8.005 \times (21 - 1.25)/2 / 10.64 \]
\[ x = 7.43 \text{ ft} \]

REACTION FORCE (ASSUME HINGED @ X - ZERO MOMENT)

\[ \Sigma M_x = J_S \times (h - Ze) / 2 \times \left[ \left( h - Ze \right) / 3 + x \right] - pp \times x^2 / 2 - R_i \left( h - A_1 + x \right) = 0 \]
\[ = 8.005 \times (21 - 1.25)/2 \times \left[ (21 - 1.25)/3 + 7.43 \right] - 10.64 \times 7.43^2 / 2 - R_i (21 - 10 + 7.43) \]
\[ R_i = 44.17 \text{ kips} \]

ZERO SHEAR

\[ \Sigma V = 0 = J_S \left( h - Ze \right) / 2 - pp \times Z - R_i \]
\[ = 8.005 \times (21 - 1.25)/2 - 10.64 \times 2 - 44.17 \]
\[ Z = 3.28 \text{ ft} \quad + \quad z_i = 24.28 \text{ ft} \]
MAX MOMENT

\[
\Sigma M = \frac{5}{12} \left( h - 2a \right) \left( \frac{h - 2a}{3} + 3 \right) \cdot \frac{t}{2} - \frac{2}{\pi} (h - a) \cdot (h - a) - x
\]

\[
= 8.005 \left( h - 1.25 \right) \left( \frac{21 - 1.25}{3} + 3.23 \right) - 10.04 \cdot \frac{3}{2} - 4.47 \left( 21 \cdot 0.5 \cdot 3.14 \right)
\]

\[
M_{max} = 91.71 \text{ k-FT}
\]

\[
S = 38.21 \text{ k}\text{F}
\]

EMBEDMENT DEPTH

\[
\Sigma M = M_3 + PP \cdot \phi \cdot \left( \frac{D}{2} + h - A_1 \right) - S \cdot \left[ \sqrt{h - A_1} + q - 2c \right] \cdot \left( h - A_1 \right)^2 / 2 - 2S \cdot \phi \cdot (h - A_1)^3 / 2 = \phi
\]

\[
= 91.71 + 10.64 \cdot D / 2 + 11 \right) - 5 \cdot \left[ 0.11 \cdot 13 \left( 10 \right) + \left( 0.75 + 0.07 \right) - 2 \times 0.857 \right] \times \left( D / 2 + 11 \right)^3 / 2 - 2 \times 5 \times 0.11 \times 3 / 6
\]

\[
= 25.13 - D / 2 + 11 \right) \rightarrow D = 2.09 \text{ FT}
\]

STAGE III

\[
\Delta h = \frac{15 \times 0.11 + 16 \times 0.12}{31}
\]

\[
= 0.1152 \text{ kCF}
\]

\[
C_{ave} = \frac{15 \times 0.5 + 16 \times 1.75}{31}
\]

\[
= 1.145 \text{ kSF}
\]

\[
C_0 = 1.75 \text{ kSF}
\]

\[
9e \text{ STRIP} \quad \theta_2 = \tan^{-1} \left( 60 / 31 \right) = 1.094
\]

\[
\theta_1 = \tan^{-1} \left( 50 / 31 \right) = 1.016
\]

\[
9e = 10 / 6 \times (1.094 - 1.016) = 0.247 \text{ kSF}
\]
**STABILITY NUMBER, Ns**

\[ N_s = \frac{\gamma H}{c} \]
\[ = 0.1152 \times 31 / 1.145 = 3.12 \]

**USE PRESSURE DISTRIBUTION**

\[ q_h = 0.98 \ H \]

\[ q_h = 0.9 \times 0.1152 \times 31 \times 5 \]
\[ = 7.14 \text{ Ksf} \]

\[ q + q_e = 0.997 \text{ Ksf} \]

\[ p_p = (8c - (q + q_e)) \times b_f \quad \text{- VACATE SOIL PRESSURE BELOW CUT} \]

\[ = (8 \times 1.75 - 0.997) \times 1 = 13.00 \text{ Ksf} \]

**REACTION FORCES**

\[ \Sigma M_{R_1} = 0 = 7.14 \times 7.75/2 \times (7.75/3 + 12.25) + 7.14 \times 12.25^2/2 + 0.997 \times 5 \times 20^2/2 - R_1 (10) \]

\[ R_1 = 194.31 \text{ KIPS} \]

\[ \Sigma M_{R_2} = 7.14 \times 7.75/2 \times (7.75/3 + 23.25) + 7.14 \times 15.5 \times 1.5 \times (7.75 + 7.75) + 7.14 \times 7.75^3/3 + 0.997 \times 5 \times 31^2/2 - 194.31 \times (31 - 10) - R_2 (11) = 0 \]

\[ R_2 = 80.71 \text{ K} \]

**ZERO SHEAR**

\[ \Sigma V = 0 = 194.31 + 80.71 - 7.14 \times 7.75/2 - 7.14 \times 15.5 - 5 \times 0.997 \times z \]
\[ - 5 \times 0.1152 \times (31 - 0.82)(z - 0.75(31)) \]
\[ = 136.7 - 4.985 \times z - 0.576 \times (31 - 0.82)(z - 23.25) \]

\[ z = 25.1 \text{ FT} \]
**Max Moment**

\[
\sum M_2 = 194.31 \times (15.1 + 80.7 \times 5/4 - 7.14 \times 7.75/2 \times (25.1 - 2(7.75/3)) - 7.14 \times 15.5 \times (25.1 - 15.5) - 5 \times 0.337 \times 25.1^2/2
\]

\[
- 0.9 \times 5 \times 0.1152 \times (25.1 - 0.75 \times 3.1)^2 \times (31 - 2(3 \times 25.1))
\]

\[
M_{max} = 150.21 \text{ k-ft}
\]

\[
S = 62.59 \text{ in}^3
\]

**Embedment Depth**

\[
\sum M_{r2} = 150.2 + 13D \left( \frac{D}{2} + 11 \right) - 7.14 \times \left( \frac{11 - 7.75}{2} \right)^2/2 - 7.75 \times 7.14/2
\]

\[
\times \left( \frac{7.75}{3} + \frac{(11 - 7.75)}{2} \right) - 5 \times 0.997 \times 11^2/2
\]

\[
= 26.96 - D \left( \frac{D}{2} + 11 \right)
\]

\[
D = 2.23 \text{ ft}
\]

**Stage IV**

\[
\gamma_{ave} = (15 \times 0.11 + 25 \times 0.12)/40
\]

\[
= 0.11625 \text{ kcf}
\]

\[
C_{ave} = (15 \times 0.5 + 25 \times 1.75)/40
\]

\[
= 1.28 \text{ ksf}
\]

\[
C_l = 1.75 \text{ ksf}
\]

**Stability Number**

\[
N_s = 0.11625 \times 40/1.75 \approx 2.7
\]
\[ T_h = 0.4 \times 6 \times 5 = 0.4 \times 11625 \times 40 \times 5 \]
\[ = 9.3 \text{ ksf} \]

\[ \rho p = 1.3 \text{ ksf} \]

9e strip \[ \Rightarrow \] \[ \theta_2 = \tan^{-1}(60/40) = 0.983 \]
\[ \theta_1 = \tan^{-1}(50/40) = 0.896 \]

9e \[ = 10/\pi \times (0.983 - 0.896) \]
\[ = 0.276 \text{ ksf} \]

9t = 9 + 9e = 1.026 ksf

**REACTION FORCES**

\[ \Sigma M_{\alpha 1} = 9.3 \times 10/2 \times (10/3 + 10) + 10^2 \times 9.3/2 + 1.026 \times 5 \times 10^2/2 - R_1(10) = 0 \]
\[ R_1 = 211.1 \text{ kips} \]

\[ \Sigma M_{\alpha 2} = 9.3 \times 10/2 \times (10/3 + 20) + 9.3 \times 10^2/2 + 1.026 \times 5 \times 30^2/2 \]
\[ - 211.1 \times 10 - 10 R_2 = 0 \]
\[ R_2 = 103.15 \text{ kips} \]

\[ \Sigma M_{\alpha 3} = 9.3 \times 10/2 \times (10/3 + 30) + 9.3 \times 20 \times 20^2/2 + \\
9.3 \times 10/2 \times (2/3 \times 10) + 1.026 \times 5 \times 90^2/2 - \\
211.1 \times 30 - 103.15 \times 20 - R_3 \times 10 = 0 \]
\[ R_3 = 128.8 \text{ kips} \]

**ZERO SHEAR**

\[ \Sigma V = 211.1 + 103.15 + 128.8 - 9.3 \times 10/2 - 9.3 \times 20 - 1.026 \times 5 \times Z \]
\[ - 5 \times 0.11625 \times (40 - 0.8 Z) (Z - 30) \]
\[ = 210.55 - 5.135 - 0.58125 (40 - 0.8 Z) (Z - 30) \]
\[ Z = 34.6 \text{ ft} \]
**Max Moment**

\[ \Sigma M = 211.1 \times 24.6 + 103.15 \times 1.46 + 128.8 \times 4.6 - \\
9.3 \times 10/2 \times (34.6 - 20/3) - 9.3 \times 20 \times (34.6 - 20) - 1.026 \times 5 \times 34.6^{3/2} \\
- 0.11625 \times 5 \times 0.9 \times (34.6 - 30)^2 (40 - 34.6 (2/3)) \]

\[ M_{\text{max}} = 123.01 \text{ k. ft} \]

\[ S = 51.25 \text{ in}^3 \]

**Depth of Embedment**

\[ \Sigma M_{R_3} = 0 = 123.01 + 13 \times D (D/2 + 10) \\
- 9.3 \times 10/2 \times 10/3 - \\
1.026 \times 5 \times 10^{3/2} \\
= 22.19 - D (D/2 + 10) \]

\[ D = 2.02 \text{ ft} \]

**Min. D Based on M_{max} of All Stages**

\[ M_{\text{max}} = 150.21 \text{ (Stage III)} \]

\[ \Sigma M_{R_3} = 150.21 + 13 D (D/2 + 10) - 411.5 \]

\[ = -20 \times 10 + D (D/2 + 10) \rightarrow D_{\text{min}} = 1.84 \text{ ft} \]

**Cantilever (Not Included in Program)**

**Stage 1:**

\[ M_{c_i} = 5 \times (xh + 0.5 \times 2c) (h - z_c)^2/6 \]

\[ = 5 \times (1.11 \times 11 + 0.822 - 2 \times 0.5)(11 - 1.25)^2/6 \]

\[ M_{c_i} = 84.92 \text{ k. ft} \]

**Stage 2:**

\[ R_i = \left[ 5x \times (21 - 1.25)^2 / (21 - 1.25)^2 \times \left( 10 - 1.25 \right)^5 - 5 \times (21 - 1.25)^4 \times (10 - 1.25) + 4 \times (21 - 1.25)^5 \right] / \]

\[ \left[ 20 \times (21 - 10)^3 \right] \rightarrow R_i = 41.22 \text{ k} \]
\[ M_{c2} = 5 \ast (21 \ast 1.129 + 0.944 - 2 \ast 0.857 \ast (21 - 1.25) \frac{1}{2} + (21 - 1.25) \frac{1}{3} - 41.22 \ast (21 - 10) \]
\[ = 66.96 \text{ kN} \]

**ANCHORS**

Row 1 \( \rightarrow R_{max} = 211.11 \)

\( 2 \rightarrow R_{max} = 103.15 \)

\( 3 \rightarrow R_{max} = 128.8 \)

**Anchor Spacing = 5 ft**

**AT 7.5° ANGLE**

**Required Capacity:**

\[ U_c = \frac{R_i}{\cos \theta} \ast \frac{d}{s} \]

\[ U_1 = \frac{211.11}{\cos 7.5 \ast 5} = 212.9 \text{ k} \]

\[ U_2 = \frac{103.15}{\cos 7.5} = 104.0 \text{ k} \]

\[ U_3 = \frac{128.8}{\cos 7.5} = 129.9 \text{ k} \]

**Bounded Length:**

Assume stiff to very stiff clay.

\[ L = \frac{U}{7.85} \]

\[ L_1 = \frac{212.9}{7.85} = 27.1 \text{ ft} \]

\[ L_2 = \frac{104}{7.85} = 13.2 \text{ ft} \]

\[ L_3 = \frac{129.9}{7.85} = 16.5 \text{ ft} \]

**Unbounded Length:**

\( \psi = 0^\circ \)

\[ L_4 = 0.891 (h - d_4) \]

\[ L_{u1} = 0.891 (40 - 10) = 26.7 \text{ ft} \]

\[ L_{u2} = 0.891 (40 - 20) = 17.8 \text{ ft} \]

\[ L_{u3} = 0.891 (40 - 30) = 8.9 \text{ ft} \]

**Wales**

\[ S_{wi} = \frac{R_i d^2}{14.45} = 0.347 R_i \]

\[ S_{wi} = 0.347 \ast 211.11 = 73.3 \text{ m}^3 \]

\[ S_{w2} = 0.347 \ast 103.15 = 35.8 \text{ m}^3 \]

\[ S_{w3} = 0.347 \ast 120.8 = 41.7 \text{ m}^3 \]
**KienIT Criteria**

**Stage I:**

\[ M_k = \frac{(l_k \times (h - 2c))/2 \times ((h - 2c)/3 + 2)}{2} \]

\[ = 5.375 \times (11.25)/2 \times ((11.25)/3 + 2) \]

\[ = 137.6 \text{ k. ft} \]

**Stage II:**

\[ M_{k2} = \frac{w_{ave} l^2}{3} \]

\[ w_{ave} = \left[ \left( q_{e - 2c} + 8A_1 \right) + 8(h - A1)/2 \right] \times S \]

\[ = \left[ 0.75 + 1.94 - 2 \times 1.5 + 0.1129(10) \right. \]

\[ + \left. 0.1129 \times \frac{21 - 10}{2} \right] \times 5 \]

\[ = 4.9 \text{ ksf} \]

\[ M_{k2} = 4.9 \times 11^2/3 = 65.9 \text{ k. ft} \]

**Rk**

\[ = 5 \times \left[ (q_{e - 2c} + 8A_1)(A1 - 2c)/2 + \right. \]

\[ \left. \left( q_{e - 2c} + 8A1 \right)(h - A1)^3/2 + 8(h - A1)^3/6 \right] \]

\[ = 5 \times \left[ 1.75 + 1.94 - 2 \times 1.5 + 0.1129 \times 10 \times \frac{10 - 1.25}{2} + \right. \]

\[ \left. \left( 0.75 + 1.94 - 2 \times 1.5 + 0.1129 \times 10 \times \left( 11 \right)^3/2 + 0.1129 \times 11^3/6 \right) \right] \]

\[ = 29.1 \text{ k. ft} \]
I. WALL PROPERTIES

1. Engineer: D'Amanda
2. Project: Clay Example #2
3. Date: 21 September 1991
4. The elevation of the top of the excavation is 1637.00 feet.
5. The elevation of the bottom of the excavation is 1614.00 feet.
6. The number of anchors is 2. The anchors are located as follows:
   Anchor   Elevation (feet)
   1         1630.00
   2         1620.00
7. The spacing of the soldier piles is 6.00 feet.

II. SOIL PROPERTIES

8. The elevation of the water table is 1637.00 feet.
9. The soil properties are as follows:
   Soil Type   Elev   Unit Wt   Friction Angle or Cohesion
   clay      1637.0   0.0626   0.75
10. The slope of the ground behind the wall is 0 degrees.
11. The surcharge load is 0.000 ksf.
12. The strip load is 0.00 ksf, 0.00 feet long, and located 0.0 feet from the wall.

III. WALL ANALYSIS RESULTS

13. Estimated width of the soldier pile is 0.75 feet.
14. Factor of safety for passive resistance is 1.5.
15. The wall was excavated 1.0 feet below the proposed anchor location.
### 16. STAGE ZERO MAXIMUM SECTION EMBEDMENT REACTION(S)

<table>
<thead>
<tr>
<th>SHEAR MOMENT (ft)</th>
<th>MODULUS (k-ft)</th>
<th>DEPTH (in^3)</th>
<th>DEPTH (ft)</th>
<th>REACTION (kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.0</td>
<td>---</td>
</tr>
<tr>
<td>23.5</td>
<td>5.39</td>
<td>2.24</td>
<td>5.1</td>
<td>R1 = 4.26</td>
</tr>
<tr>
<td>20.0</td>
<td>41.81</td>
<td>17.42</td>
<td>4.4</td>
<td>R1 = 65.60, R2 = 65.84</td>
</tr>
</tbody>
</table>

**NOTE:** Stage 1 moment based on Kiewit criteria is 0.0 kip-ft.
Stage 2 moment based on Kiewit criteria is 16.5 kip-ft and reaction force is 2.5 kips.

**NOTE:** Minimum depth of embedment based on maximum moment is 4.4 feet.

**NOTE:** NYCTA recommends minimum penetration depth of six feet.

**NOTE:** A effective stress analysis approach was used.

**END OF ANALYSIS**
CLAY EXAMPLE PROBLEM #2

(WTR TABLE AT GRD LEVEL)

ESTIMATED PILE WIDTH 8' OR 0.75 IT
FACTOR OF SAFETY VS PASSIVE
RESISTANCE 1.5
OVEREXCAVATE BELOW ANCHOR 1 FT

STAGE I

\[ \gamma_b = 125 - 62.9 = 62.6 \text{pcf} \]
\[ \gamma_w = 62.4 \]

TENSION ZONE

\[ \gamma_b \cdot z_t + \gamma_w \cdot z_t - 2c = \phi \]
\[ z_t = \frac{2c}{(\gamma_b + \gamma_w)} \]
\[ = \frac{2 \times 0.75}{(0.0626 + 0.0629)} \]
\[ z_t = 12 \text{ ft} \]
\[ h = 8 \]
\[ z_t > h \rightarrow \text{NEGLECT STRESSES W/IN TENSION ZONE.} \]
\[ \therefore M_{\text{max}} = \phi \]

STAGE II

TENSION ZONE:

\[ z_t = 12 \]
**STRESSES – FORCES**

\[
P_a = (\phi h - Z_c)(h - Z_c)/2 + S
\]
\[
= (0.125 \times 18 - 2 \times 0.75)(18 - 12)/2 + S
\]
\[
= 13.5 \text{ Kips}
\]

\[
PP = (6SF_s \times (\phi h - Z_c))b_f
\]
\[
= (6 \times 0.75/1.5 - (0.125 \times 18 - 2 \times 0.75)) \times 0.75
\]
\[
= 1,687.5 \text{ Ksf}
\]

**NET ZERO FORCES ON EMBEDDED PILE**

\[
\sum F_y = 0 = 13.5 - 1,687.5 X
\]
\[
X = 8 \text{ FT}
\]

**REACTION FORCE**

\[
\sum M_x = 0 = P_a((h - Z_c)/3 + X) - PP \times X^2/2 - R_1(h - A_1 + X)
\]
\[
= 13.5(14 - 10)/3 + 8 - 1,687.5 \times 8^2/2 - R_1(10 - 7 + 8)
\]
\[
R_1 = 4.26 \text{ Kips}
\]

**ZERO SHEAR**

\[
\sum V = 0 = 13.5 - 1,687.5 Z - 4.26
\]
\[
Z = 5.5 \text{ FT} + 18 = 23.5 \text{ FT}
\]

**MAX. MOMENT**

\[
\sum M_x = 13.5 \times (6/3 + 5.5) - 1,687.5 \times 5.5^2/2 - 4.26 \times (11 + 5.5)
\]
\[
M_{max} = 544 \text{ KFt}
\]
\[
S = 2.27 \text{ in}^3
\]
**Depth of Embedment**

\[ \sum M_B = 0 = 5.44 + 1.6875D(D/2 + 11) - 13.5(11 - 6/3) \]
\[ = D(D/2 + 11) - 68.73 \]
\[ D = 5.1 \text{ FT} \]

**Stage III**

\[ N_s = \delta h/c = 0.0626 \times 23/0.75 \]
\[ = 1.9 \]
\[ J_h = 0.4 \gamma h * s \]
\[ = 0.4 \times 0.0626 \times 23 \times 6 \]
\[ = 3.46 \]

**Reaction Forces**

\[ \sum M_{RA} = 3.46 \times 5.75/2 \times (5.75/3 + 11.25) + 0.0624 \times 17/2 \times 6(17/3) \]
\[ + 3.46 \times 11.25 \times 2/ - 10R_1 = 0 \]
\[ R_1 = 65.65 \text{ kips} \]

\[ \sum M_{BASE} = 3.46 \times 5.75/2 \times (5.75/3 + 17.25) + 3.46 \times 11.25 \times (11.5) \]
\[ + 0.0624 \times 233/6 \times 6 + 3.46 \times 5.75/2 \times 73(5.75) \]
\[ - 16 \times 65.65 - 6 R_2 = 0 \]
\[ R_2 = 65.87 \text{ kips} \]

**Zero Shear**

\[ \sum V = 0 = 65.65 + 65.87 - 3.46 \times 5.75/2 - 3.46 \times 11.5 \]
\[ - 6 \times 0.0624 (23 - 0.82)(2 - 17.25) - 0.0624 \times 6 \times 2/2 \]
\[ = 21.78 - 0.3744 (23 - 0.82)(2 - 17.25) - 0.1872 \times 2 \]
\[ Z = 20 \text{ FT} \]
**Max Moment**

\[
\Sigma M_z = 65.65(13) + 65.87(3) - 3.46 \times 5.75/2 \times (20 - 7.5 \times 5.75) \\
- 3.46 \times 11.5 \times (20 - 11.5) - 0.0624 \times 6 \times (20)^{3/6} - 6 \times (0.0624)(20 - 7.5)^2 \times \frac{1}{2} \\
\frac{2.5 - 7.5}{(20)}
\]

\[M_{\text{max}} = 41.88 \text{ k ft} \sqrt{V}
\]

\[S = 17.45 \text{ in}^3
\]

**Emplacement Depth**

\[
\Sigma M_{z} = 0 = 41.88 + (6 \times 0.75/(1.5 + 2 \times 0.75)) \times \\
- 0.75 D(D/2 + 6) - 0.25/2 \times 3.96 \\
- 3.46 \times 5.75/2 (5.75/3 + 0.25) \\
- 17 \times 0.0624 \times 6 (6)^{1/2} - 0.0624 \times 6 \times 6 \times 6 \times (3.96)
\]

\[= 35.94 - D(D/2 + 6) \rightarrow D = 4.4 \text{ ft} \sqrt{V}
\]

**Cantilever Analysis** *(not included W/I program)*

**Stage II:**

\[
R_c = 6 \times (0.125 \times 10 - 2 \times 0.75) \times 6 \times 2 \times \\
(6/5 - (12 - 7)/4) / (6/8 - 7)^3
\]

\[= 0
\]

\[M_c = 13.5 \times 6 / 3 - 0 = 27 \text{ k ft} \sqrt{V}
\]

**Kiewit Criteria:**

**Stage II:**

\[
M_k = \omega l^2/8 = \frac{P_z}{h-z_c} \times (h - z_c)^2/9
\]

\[= 13.5 \times (18 - 12)/9 = 16.5 \text{ k ft} \sqrt{V}
\]

\[R_k = \frac{P_z (h-z_c)/3}{h - h_1} = \frac{13.5(18 - 12)/3}{(18 - 7)}
\]

\[= 2.45 \text{ k ft} \sqrt{V}
\]

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New York City Transit Authority (NYCTA), Engineering Department, Civil Engineering and Architectural Division, Field Design Standards, 1974.


