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

BY

KEVIN J. D'AMANDA

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

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

BY

KEVIN J. D'AMANDA

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

ACKNOWLEDGEMENTS

I wish to express my gratitude to Dr. Townsend, Dr. Davidson, Dr. McVay, and Dr. Bloomquist for their support and for making their classes both challenging and interesting while still enjoyable. Also to Jim Hussin and the personnel at Hayward Baker for their assistance in helping me prepare this program. Lastly to the rest of the dungeon rats,

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?" Weintrub;
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.

BIOGRAPHICAL SKETCH

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.

Lieutenant D'Amanda's initial duty assignment was as an Assistant Resident Officer in Charge of Construction at Naval Air Station Atlanta from March 1985 to April 1988. In April 1988, he reported to Naval Mobile Construction Battalion Sixty-Two where he served as Material Liaison Officer and as Assistant Operations Officer. After the decommissioning of the battalion in July 1989, he reported in Navy Support Facility, Diego Garcia as the Public Works Planning Officer from October 1989 to November 1990. After which, he reported to the University of Florida to pursue a Master's Degree in Geotechnical Engineering.

Lieutenant D'Amanda is a registered engineer in the states of Minnesota and Florida. Upon graduation, he will report to Commander, Naval Construction Battalions, U.S. Atlantic Fleet, at Norfolk, Virginia for duty as Assistant Special Operations Officer.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

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.

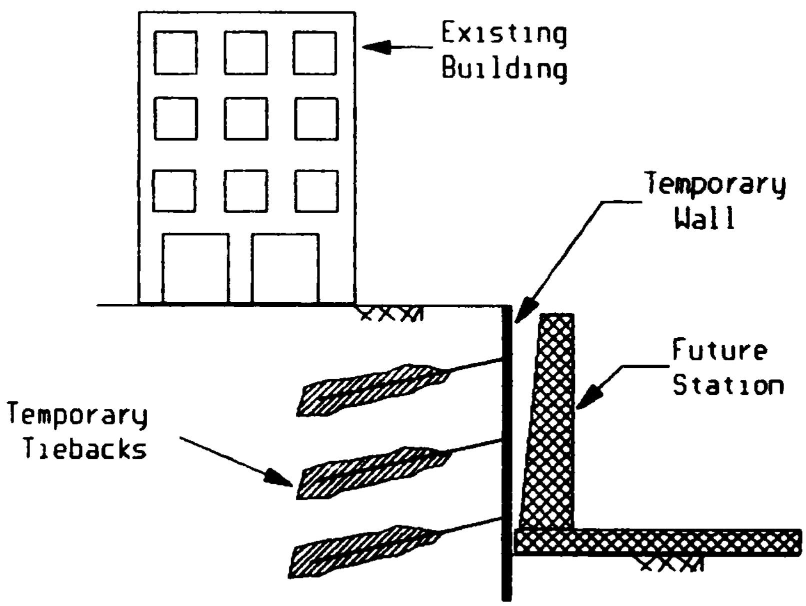


Figure 1.1
Tieback Soldier Pile and Lagging Wall for a Cut-and-Cover Station in Philadelphia (FHWA/RD-82/047, 1982)

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 Brain 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.

CHAPTER TWO

BRACED EXCAVATIONS AND TIEBACKS

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)

Step No.	Activity	Consideration
1	Explore and test subsoil.	
2	Select dimensions of excavation.	Structure size and grade requirements, depth to good soil, depth to meet stability requirements.
3	Survey adjacent structures and utilities.	Size, type, age, location, and condition.
4	Establish permissible movements.	
5	Select bracing and construction sequence.	Local experience, cost, time available, type of wall, depth of wall, type and spacing of bracing, and dewatering sequence.
6	Predict movements caused by excavation and dewatering.	
7	Compare predicted with permissible movements.	
8	Alter bracing and construction scheme, if needed.	
9	Monitor construction and alter bracing and construction as required.	

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 str... 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, <u>Tiebacks</u>, provides detailed guidance and design procedures for tiebacks.

CHAPTER THREE

DESIGN THEORY

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.

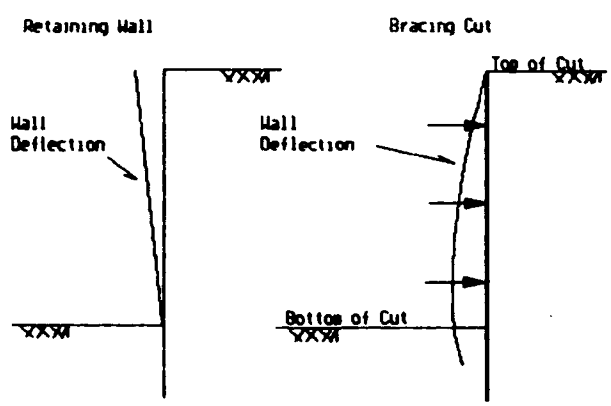


Figure 3.1
Nature of Yielding of Retaining Wall and
Braced Cut (Das, 1990)

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).

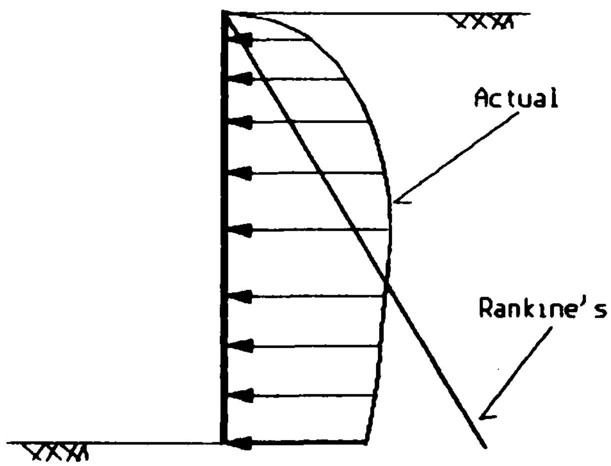


Figure 3.2
General Pressure Distribution on Braced Excavation (Cernica, 1982)

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 $0.4\gamma H$. The value of $0.4\gamma H$ is used within the program. The stability number is calculated as $N_s = \gamma H/c$. Where γ 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)

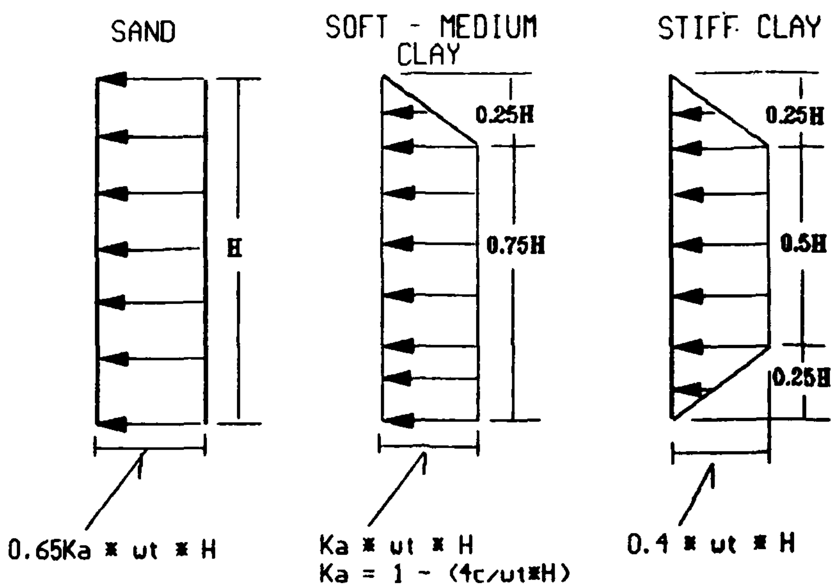


Figure 3.3
Pressure Distributions on Braced Excavations
(NAVFAC DM-7.2)

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 $0.2\gamma H$ 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 $0.15\gamma H$ for a thirty foot cut, $0.2\gamma H$ for a forty to fifty foot cut, and $0.23\gamma H$ 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 $z_t = (2*c-q)/\gamma$.

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.

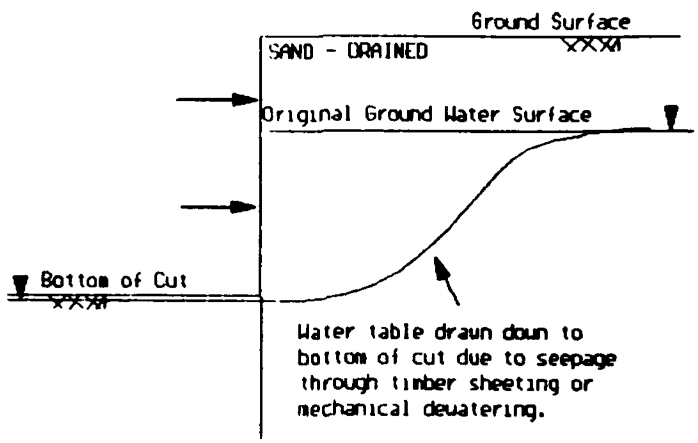


Figure 3.4
Draw Down of Ground Water Table in Sands due to Natural Seepage or Mechanical Dewatering (NYCTA, 1974)

3.4 Total versus Effective Stress Analysis

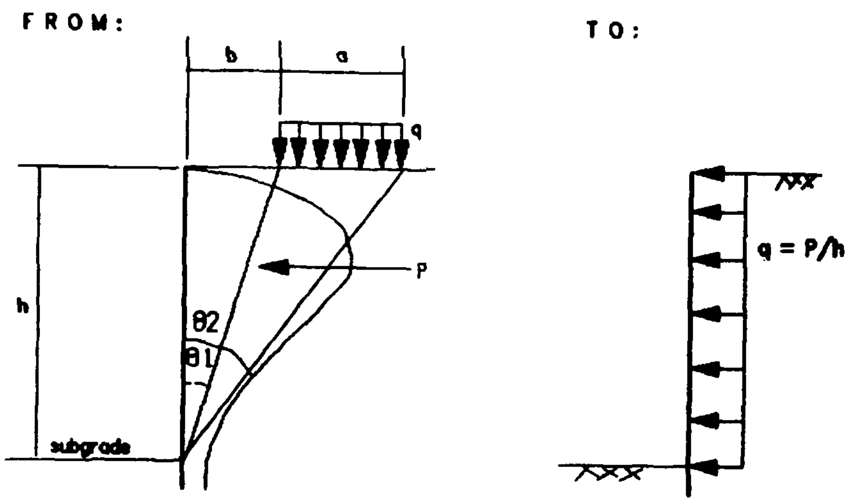
Some question on how to analyze the wall is raised when the ground water table is located above the bottom of the excavation in clay layering. The apparent lateral earth pressure envelopes proposed by Peck are based on empirical data from total stress analyses. The use of a buoyant unit weight rather 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.



$$P = 2 q * h / pi * (\theta 2 - \theta 1)$$
$$\theta 2 = \arctan [(a + b) / h]$$
$$\theta 1 = \arctan [b / h]$$

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 ($3*b_f$) 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.

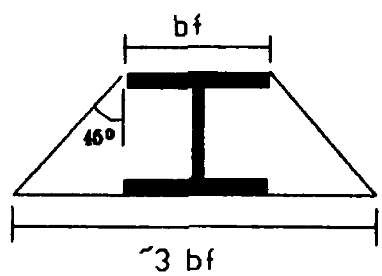


Figure 3.6
Effective Width of Soldier Pile that Passive Pressure Acts Upon (NYCTA, 1974)

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 $w*l^2/8$. 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.

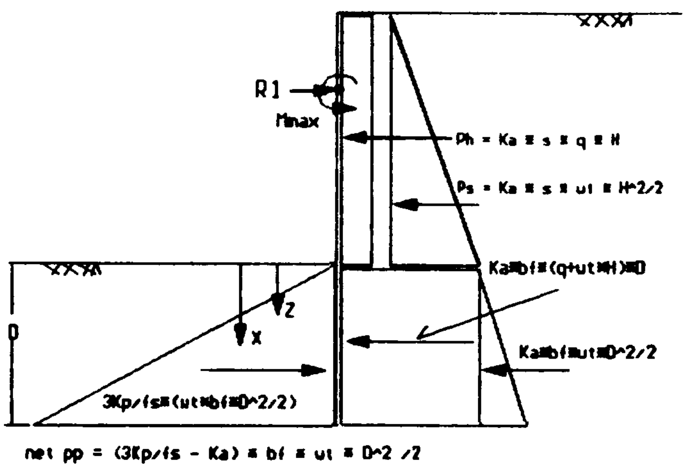


Figure 3.7
Force Diagram for Stage Two of Construction in Sands

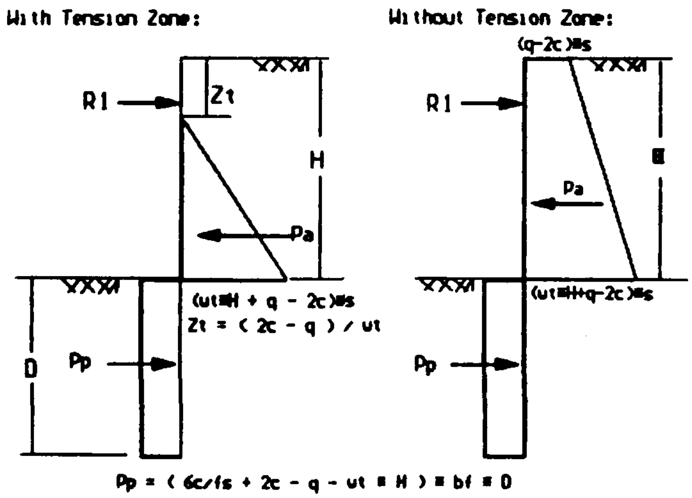


Figure 3.8
Force Diagram with and without a Tension Zone for Stage Two of Construction in Clays

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 $M = w*l^2/9$. Where w is the average pressure on the span from the first anchor to the bottom of the cut and l 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.

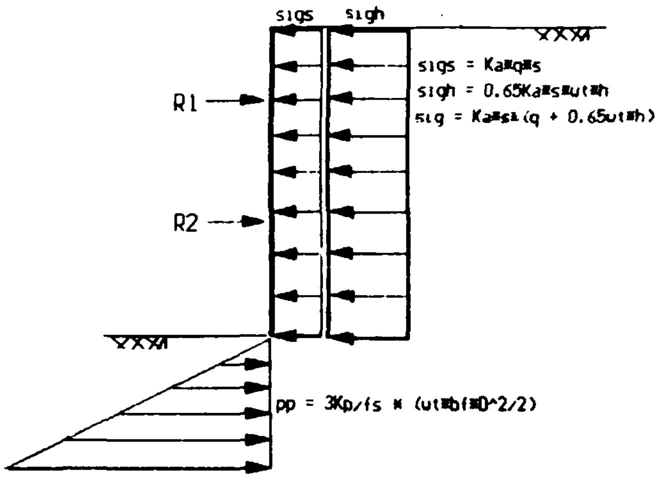


Figure 3.9
Pressure Diagram for Stage Three of Construction in Sands

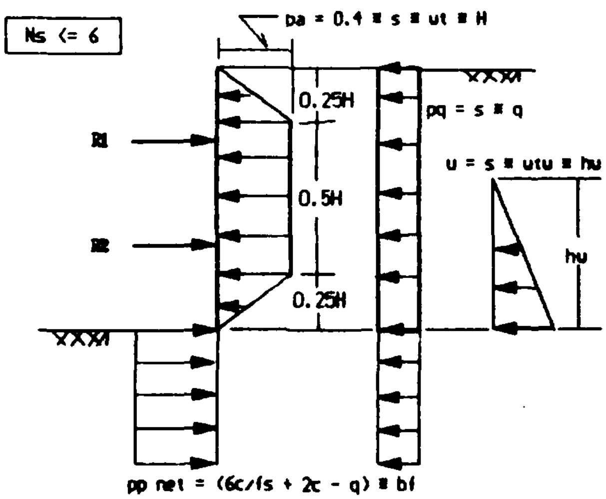


Figure 3.10
Pressure Diagrams for Stage Three of Construction in Stiff Clays

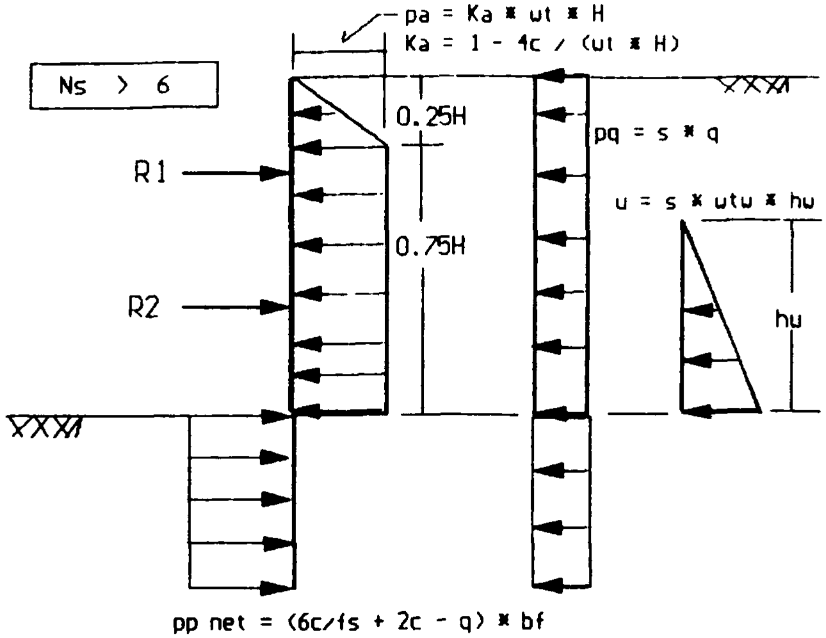


Figure 3.11
Pressure Diagram for Stage Three of Construction in Soft to Medium Clays

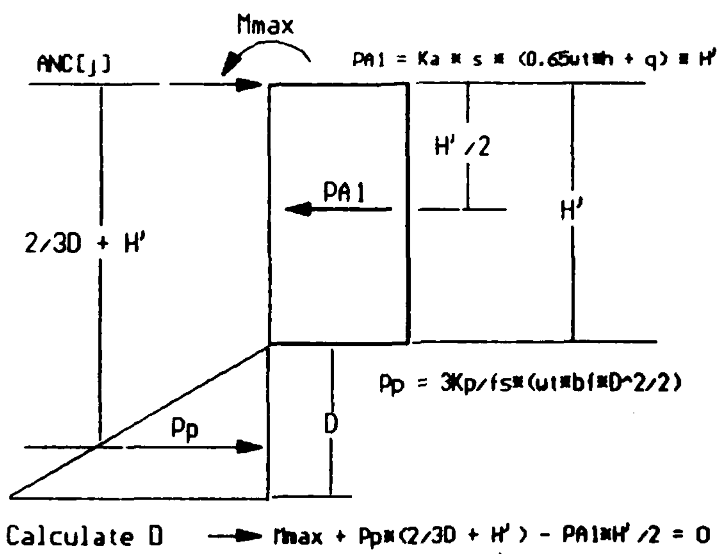


Figure 3.12
Force Diagram for Determining the Embedment Depth in in Sand Assuming Fixity about the Last Anchor Location

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 an 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 calculated 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

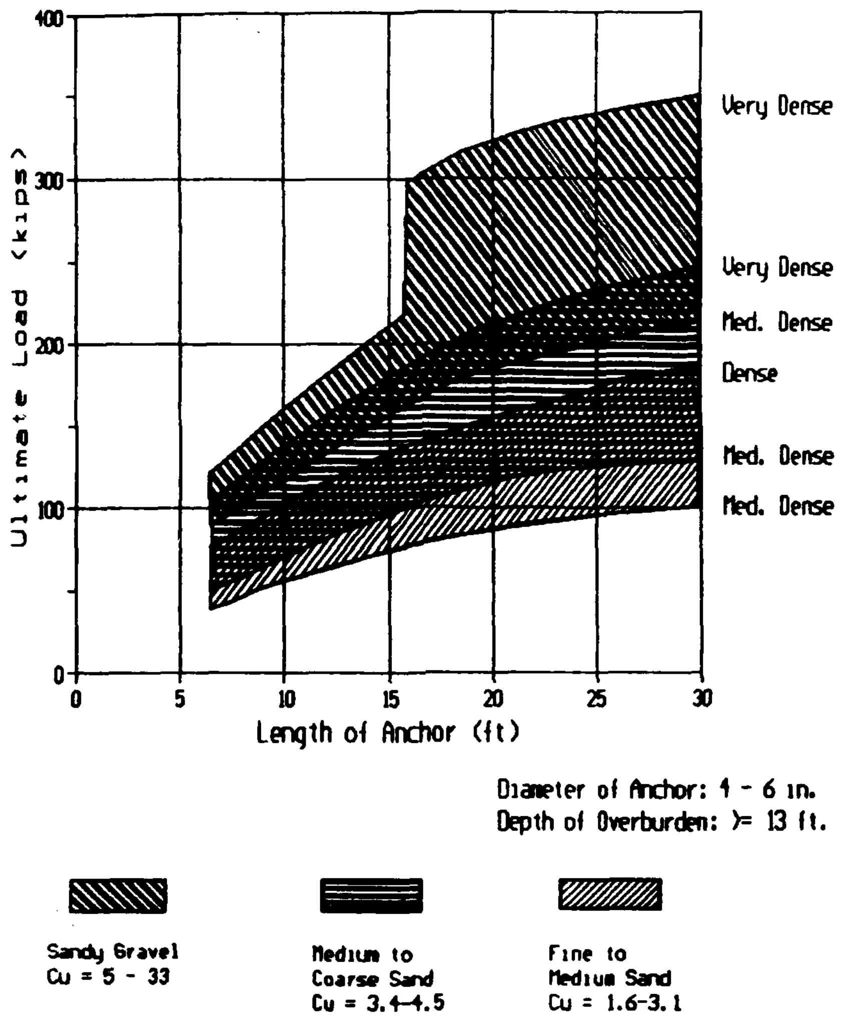


Figure 3.13
Load Capacity of Anchors in Cohesionless Soil Showing the Effects of Relative Density, Gradation, Uniformity, and Anchor Length (FHWA/RD-75/128, 1976)

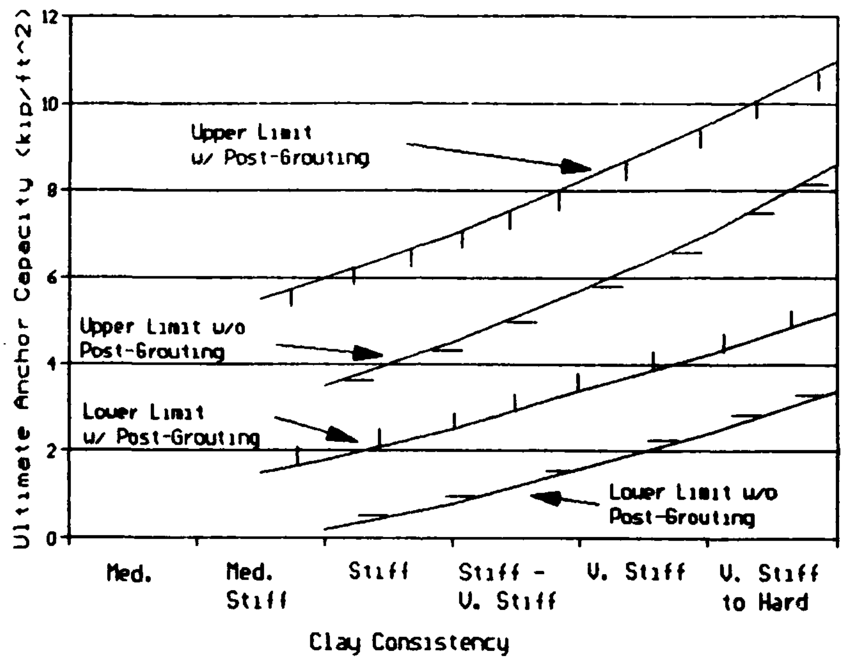


Figure 3.14
Effect of Post-Grouting on Anchor Capacity in Cohesive Soils (FHWA/RD-75/128, 1976)

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.

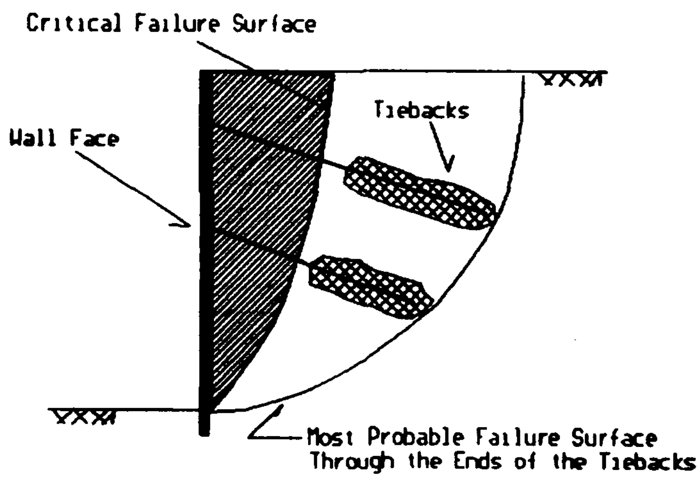


Figure 3.15
Determination of the Unbonded and Total Tieback Length (FHWA/RD-82/047, 1982)

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 3.1
Recommended Thickness of Wood Lagging, Construction Grade Lumber
(FHWA/RD-75/128, 1976)

Soil Description	Unified Classification	Depth	Recommended Thickness (inches) of Lagging (roughcut) for Clear Sapans of: 5'	6'	7'	8'	9'	10'
COMPETENT SOIL:								
Silts to fine sand and silt above water table.	ML, SM-ML							
		0' to 25'	2	3	3	3	4	4
Sands and gravels (medium dense to dense).	GW, GP, GM, GC, SW, SP, SM							
		25' to 60'	3	3	3	4	4	4
Clays (stiff to very stiff): non-fissured.	CL, CH							
Clays, medium consistency and $\gamma H/Su < 5$.	CL, CH							
DIFFICULT SOILS:								
Sands and silts, loose.	SW, SP, SM							
Clayey sands (medium dense to dense) below water table.	SC	0' to 25'	3	3	3	4	4	5
Clays, heavily overconsolidated: fissured.	CL, CH	25' to 60'	3	3	4	4	5	5
Cohesionless silt or fine sand and silt below water table.	ML, SM-ML							
POTENTIALLY DANGEROUS SOIL:								
Soft clays, $\gamma H/Su > 5$.	CL, CH	0' to 15'	3	3	4	5	--	--
Slightly plastic silts below water table.	ML	15' to 25'	3	4	5	6	--	--
		25' to 35'	4	5	6	--	--	--
Clayey plastic silts below water table.	SC							

Note: In the category of potentially dangerous soils, use of lagging is questionable.

CHAPTER FOUR

COMPUTER PROGRAM

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.

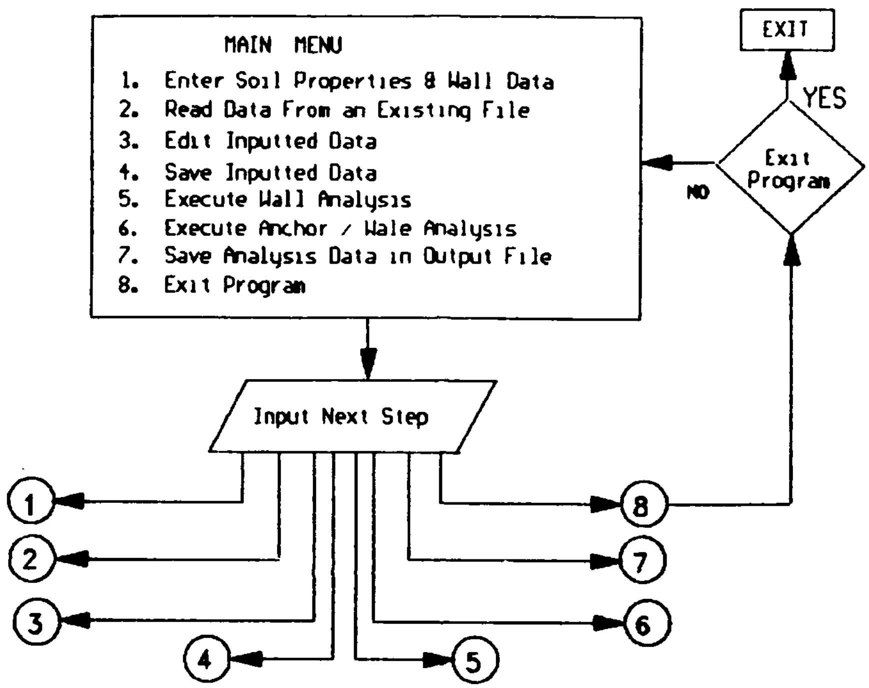
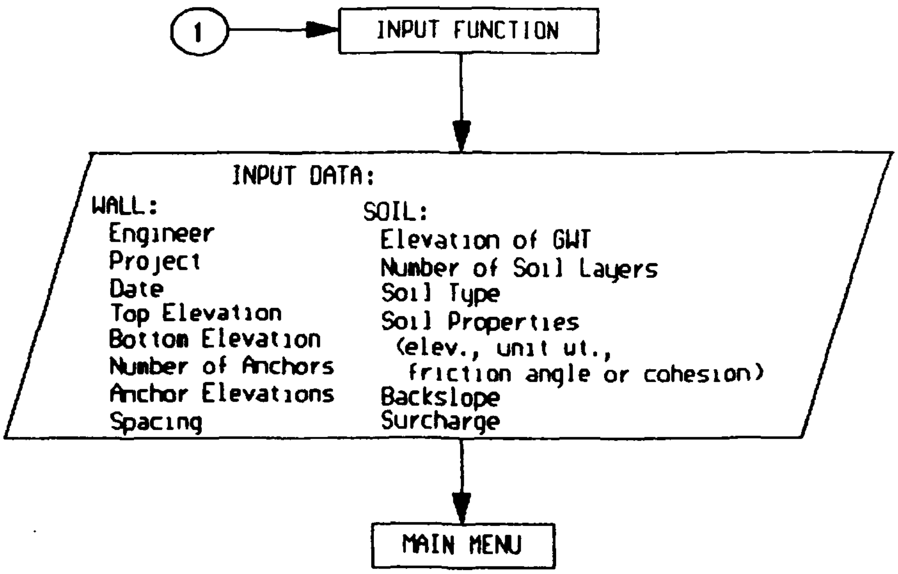


Figure 4.1
Computer Program's Flow Chart



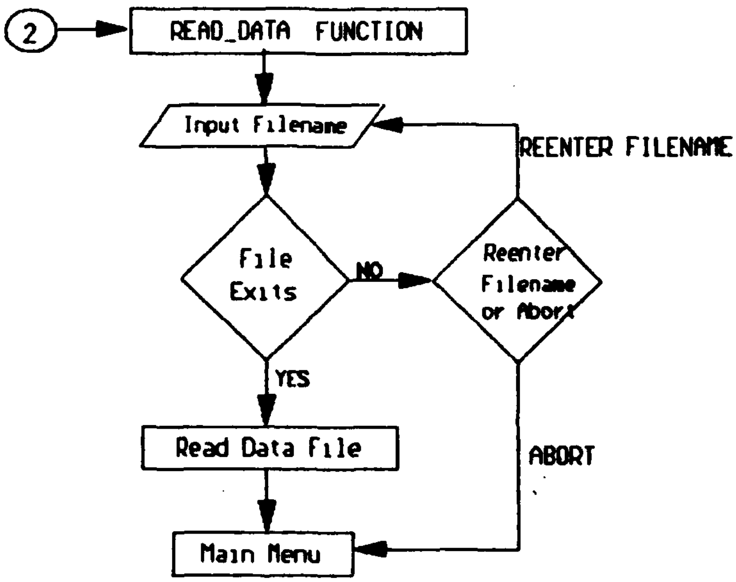


Figure 4.1 (Continued)
Computer Program's Flow Chart

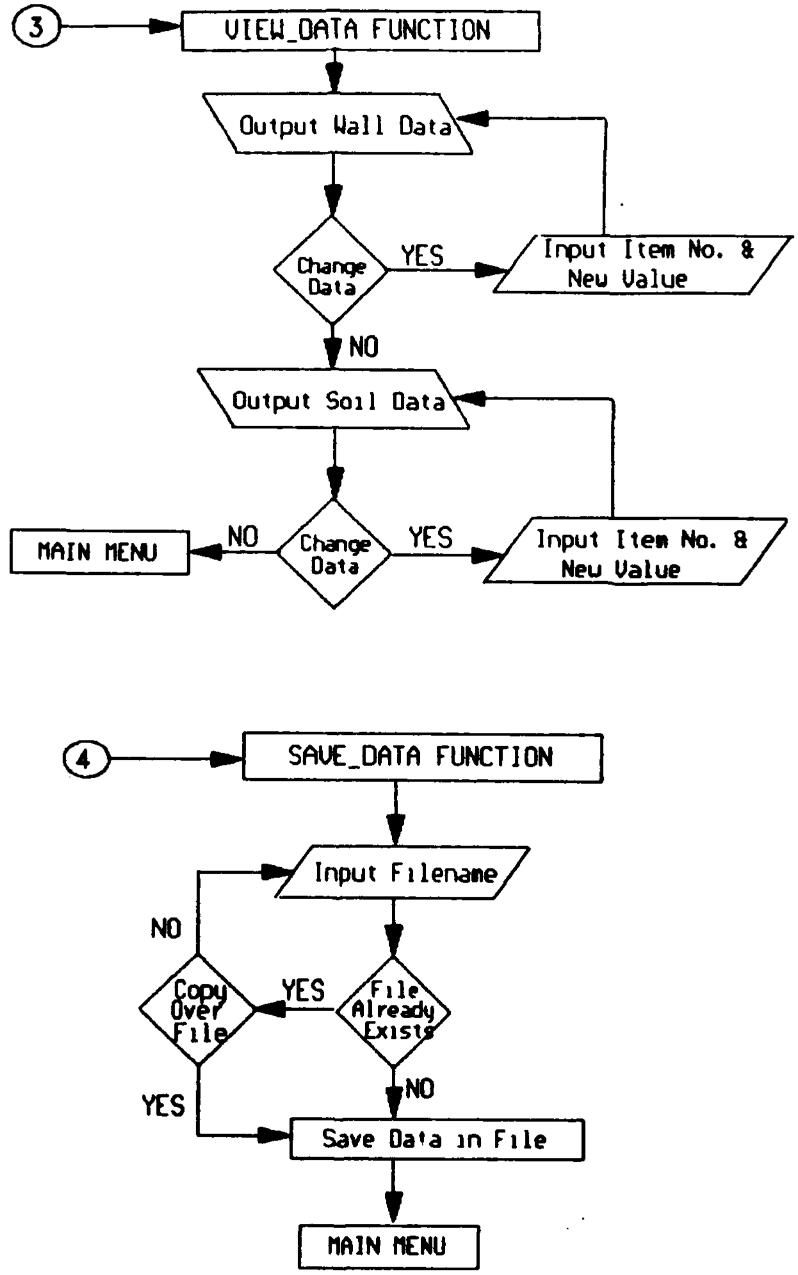


Figure 4.1 (Continued)
Computer Program's Flow Chart

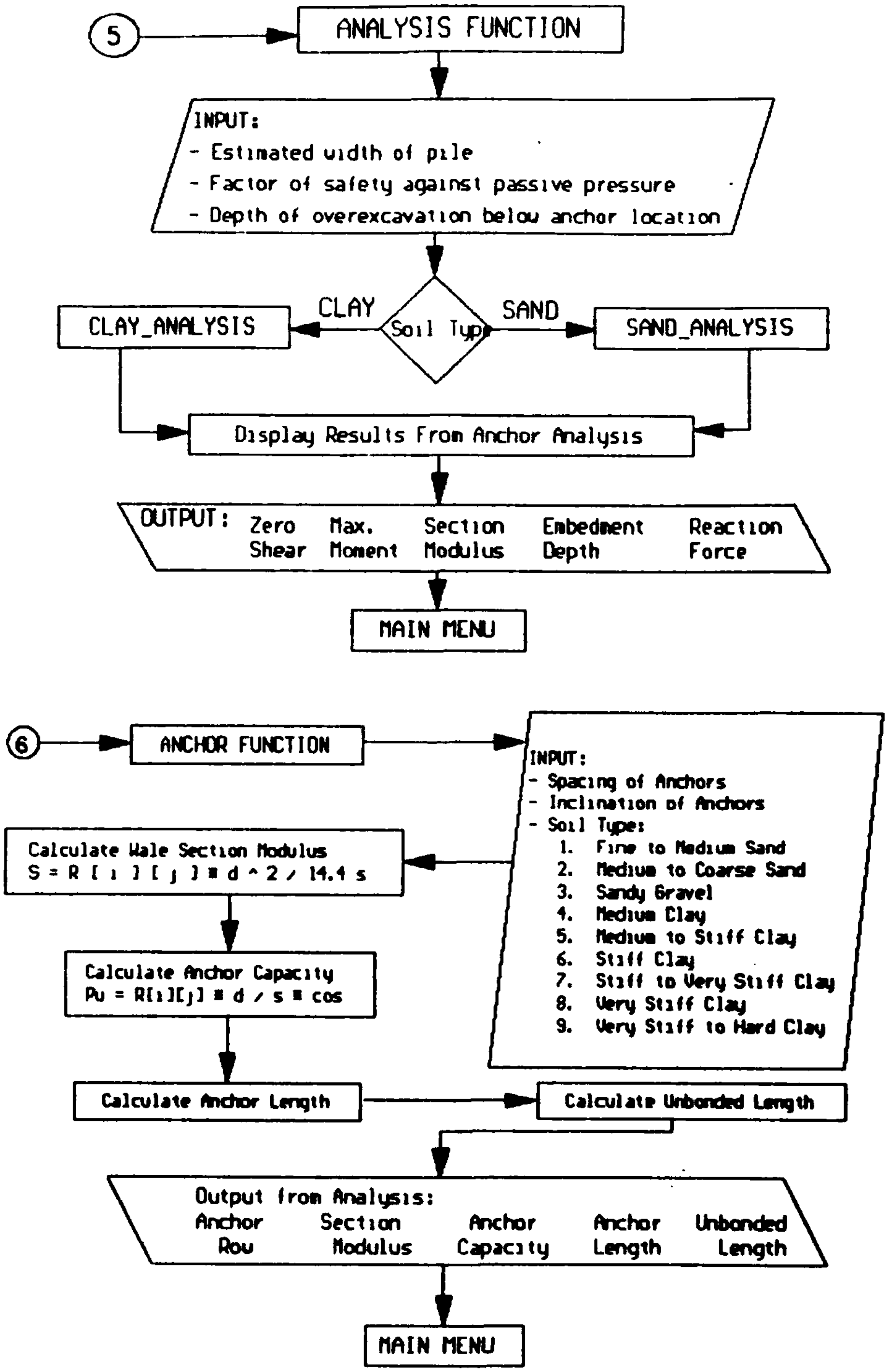


Figure 4.1 (Continued)
Computer Program's Flow Chart

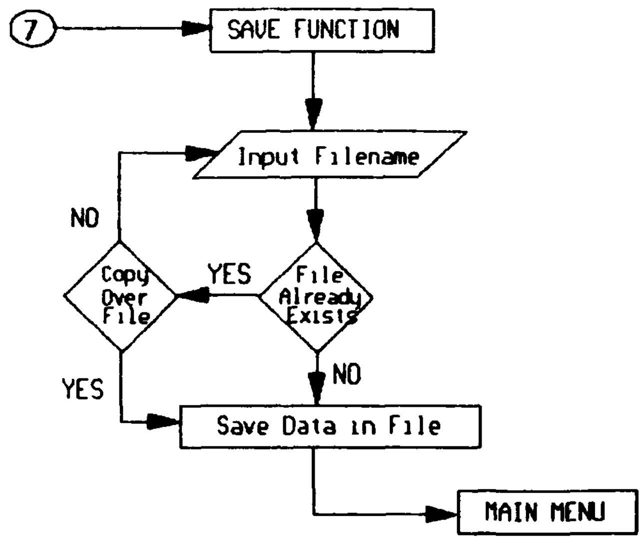


Figure 4.1 (Continued)
Computer Program's Flow Chart

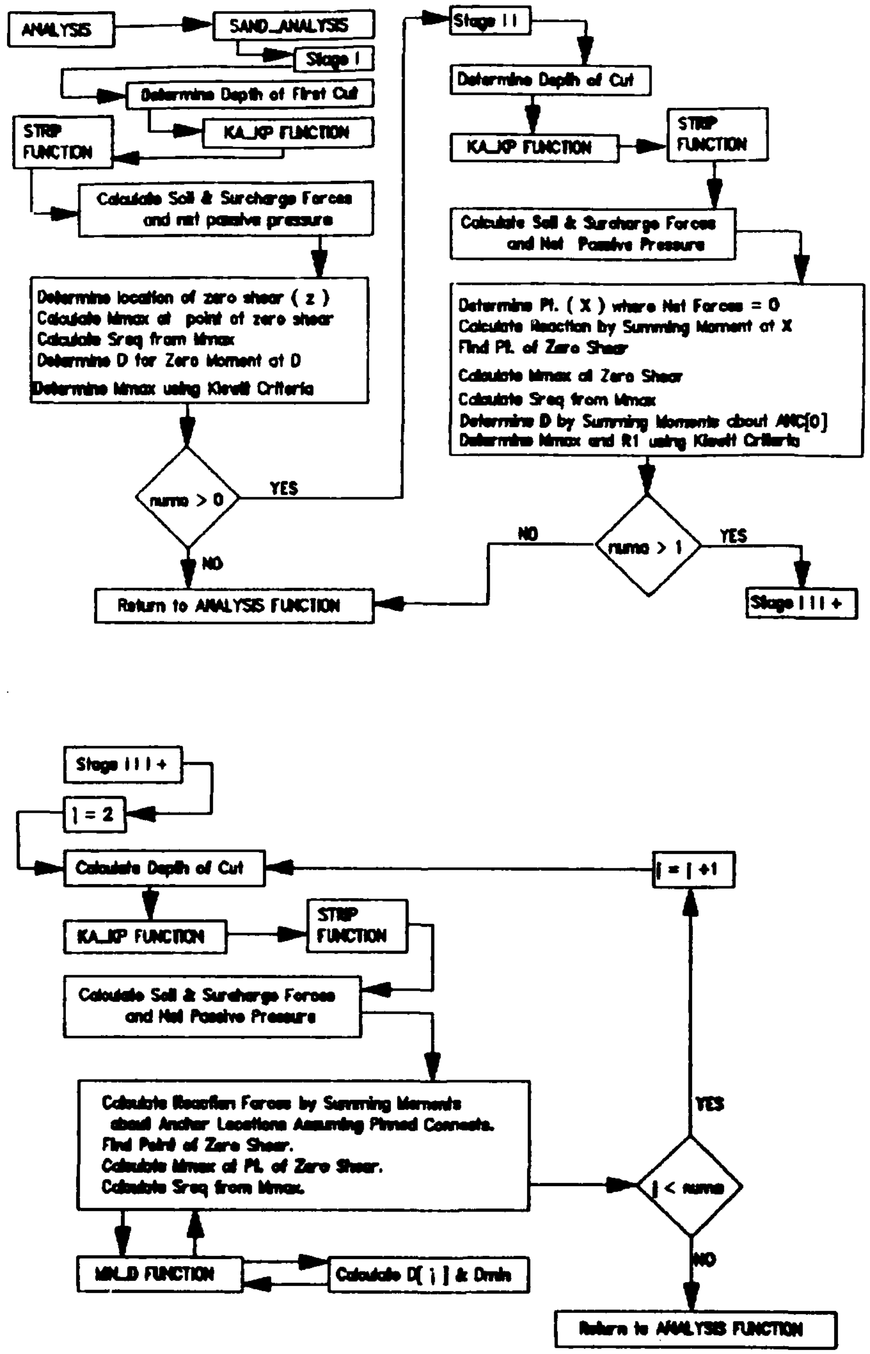


Figure 4.1 (Continued)
Computer Program's Flow Chart

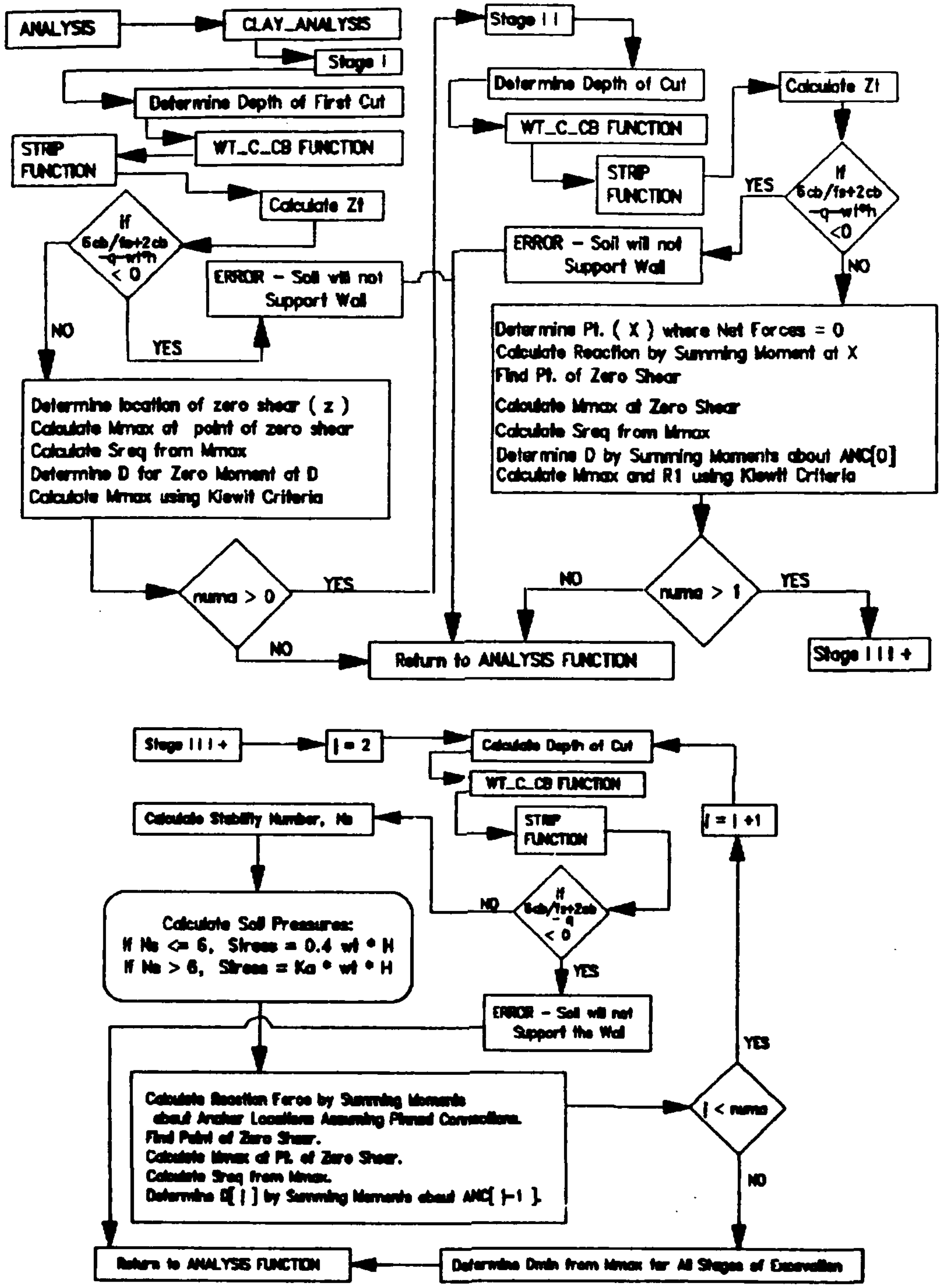


Figure 4.1 (Continued)
Computer Program's Flow Chart

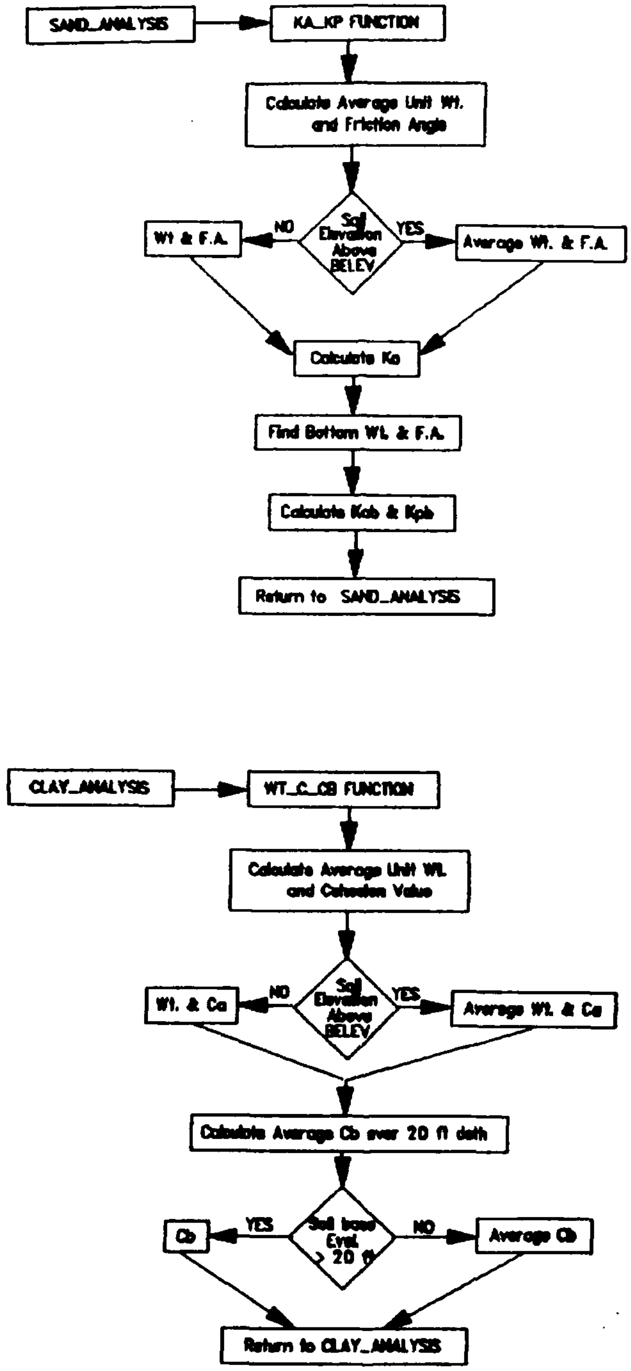


Figure 4.1 (Continued)
Computer Program's Flow Chart

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/fs + 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:

$c_{av} = [\ \gamma_s * K_s * H_s^2 * \tan\phi + (H-H_s) * n' * q_u\ ] / 2H.$

Where, H = total height of the cut,

H_s = height of the sand layer,

γ_s = unit weight of the sand layer,

K_s = lateral earth pressure coefficient for the sand layer (~1),

ϕ = 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 Φ'). 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

M A I N   M E N U

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.

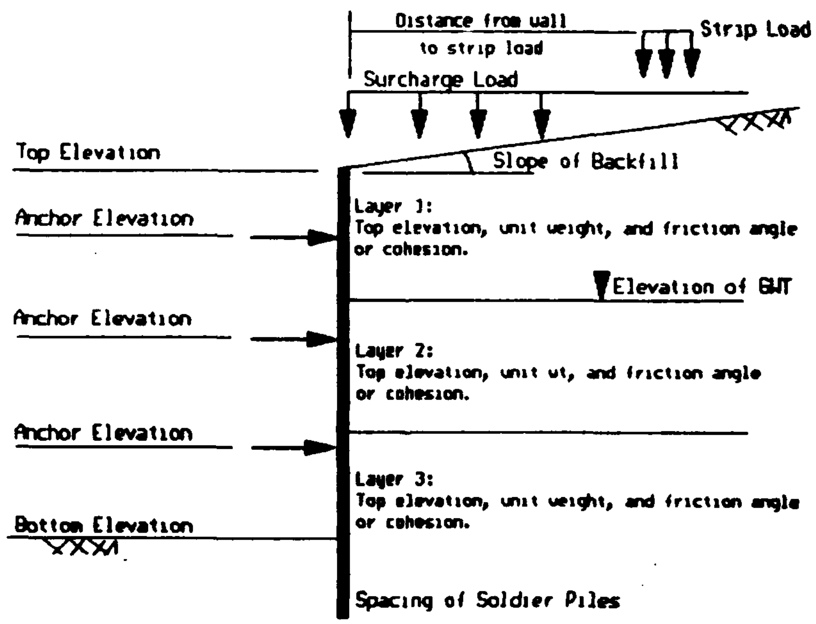


Figure 5.2
Input Variables for Wall Analysis

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:

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	4 - 8
5	Medium stiff clay	9 - 11
6	Stiff clay	12 - 15
7	Stiff to very stiff clay	16 - 20
8	Very stiff clay	21 - 30
9	Very stiff to hard clay	> 30

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.

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

I. W A L L   P R O P E R T I E S

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. S O I L   P R O P E R T I E S

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

Soil Type	Elev	Unit Wt	Friction Angle or Cohesion
sand	102.00	0.1150	38.00

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. W A L L   A N A L Y S I S   R E S U L T S

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 REACTION(S)	ZERO SHEAR (ft)	MAXIMUM MOMENT (k-ft)	SECTION MODULUS (in^3)	EMBEDMENT DEPTH (ft)	(kips)
1	12.1	55.23	23.01	10.1	---
2	21.9	20.45	8.52	5.5	R1 = 19.10
3	17.0	27.86	11.61	4.6	R1 = 42.04
					R2 = 17.17

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. A N C H O R   A N D   W A L E   R E S U L T S

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.

ANCHOR ROW	SECTION MODULUS OF WALE (in^3)	ANCHOR CAPACITY (kips)	ANCHOR LENGTH (ft)	UNBONDED LENGTH (ft)
1	58.4	84	7.4	7.0
2	23.8	34	4.0	3.8

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.

E N D   O F   A N A L Y S I S

Figure 5.3 (Continued)
Sample Output File

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.

<u>Variable</u>	<u>Definition (units)</u>
engineer	Name of engineer, for maximum of 40 characters.
project	Project title, for maximum of 40 characters.
date	Date of report, for maximum of 30 characters.
telev	Top elevation of the excavation (ft).
belev	Bottom elevation of the excavation (ft).
numa	number of anchors used in the cut excavation.
anc[10]	Elevation of anchor for maximum of ten anchors (ft).
s	Spacing of the soldier piles (ft).
gwt	Elevation of the water table (ft).
nums	Number of soil layers.
soil_type	Type of soil. Either one for sands or two for clays.
soil[10][3]	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).
b	Slope of the ground behind the excavation (degrees).
q	Surcharge load (ksf).
bf	Estimated thickness of flange of soldier pile (ft).

fs	Factor of safety against passive resistance.
w	Depth of over-excavation below the anchor elevation for intermediate stages (ft).
d	Spacing of anchors (ft).
ang	Inclination angle the anchors are set (degrees).
type	Soil type for anchor analysis calculations.
pi	Constant value of 3.141592654.
filename	Name of file to save or read data or to save analysis, for maximum of 10 characters.
wt	Average saturated or moist unit weight of cut soil (kcf).
fa	Average Friction angle of soil (degrees).
wtb	Saturated or moist unit weight of base soil (ksf).
fab	Friction angle of base soil (degrees).
Ka	Coefficient of active earth pressure for the cut soil.
Kab	Coefficient of active earth pressure for the base soil.
Kp	Coefficient of passive earth pressure for the base soil.
sigh	Horizontal stress or force due to soil (ksf or kips).
sigs	Horizontal stress or force due to surcharge (ksf or kips).

pp	Net passive resistance pressure or force (ksf or kips).
u	Hydrostatic force or stress (kips or ksf).
ca	Undrained shear strength of cut clay soil (ksf).
cb	Average undrained shear strength of base clay soil (ksf).
Ns	Stability number of the cut for clays.
zt	Length of tension zone for clays (ft).
z[11]	Depth of zero shear from top of excavation (ft).
R[10][10]	Reaction forces for each stage of construction (kips).
M[11]	Maximum moment for a stage of excavation (kip-ft).
S[11]	Required section modulus for a stage of excavation (in^3).
D[11]	Embedment depth for a stage of excavation (ft).
Mmax	Maximum moment from all stages of excavation (kip-ft).
Dmin	Minimum embedment depth calculated using Mmax (ft).
Mk[2]	Maximum moment from Kiewit Analysis for stage one and two of sand analysis (kip-ft).
Rk	Reaction force from Kiewit Analysis for stage two of sand analysis (kips).
P[10]	Anchor force for maximum of ten reactions (kips).

sw[10]	Section Modulus of wale (in^3)
L[10]	Bonded length of anchor (ft).
ul[10]	Unbonded length of anchor (ft).
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_c_cb(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 FUNCTION
// ****************************************************************

main(void) {

// ****************************************************************
// *                            INITIALIZE VARIABLES
// ****************************************************************

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;
     anc[i] = z[i] = D[i] = M[i] = S[i] = sw[i] = P[i] = ul[i] =
     L[i] = 0; }

// ****************************************************************
// *                            MAIN MENU ROUTINE
// ****************************************************************
M:
clrscr();
cout << "\n"
<< "\t ╔═══════════════════════════════════════════════════════╗\n"
<< "\t ║                                                       ║\n"
<< "\t ║          Design of Soldier Pile and Lagging           ║\n"
<< "\t ║           In Accordance with NAVFAC DM-7              ║\n"
<< "\t ║                                                       ║\n"
<< "\t ╚═══════════════════════════════════════════════════════╝\n";
cout << "\n\n\t\t\t M A I N    M E N U\n\n";
cout << "\t\t 1.  Enter Soil Properties and Wall Data\n"
     << "\t\t 2.  Read Data From an Existing File\n"
     << "\t\t 3.  Edit Input Data\n"
     << "\t\t 4.  Save Input Data\n"
     << "\t\t 5.  Execute Wall Analysis\n"
     << "\t\t 6.  Execute Anchor\\Wale Analysis\n"
     << "\t\t 7.  Save Analysis in an Output File\n"
     << "\t\t 8.  Exit Program\n\n"
     << "\t\t\t Your Choice? -- ";
while ((i = atoi(gets(cc))) <=0 || i >=9)   {
cout << "\n\t\t" << cc << " is an incorrect response, try again."
 << "\n\a";
cout << "\t\t\t Your Choice? -- ";   }
switch (i)  {
  case 1: input(); bp = 1; break;
  case 2: read_data(); bp = 1; break;
  case 3: if (bp) view_data();
else { clrscr();
cout << "\n\n\n\tERROR - You must input or read data before you
edit them!" << "\n\t        Press 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\tERROR - 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\tERROR - 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\t   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\tERROR - 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 ERROR - You must accomplish wall analysis before
 you can save the data!"  << "\n         Press the enter to
return to the main menu.\a";
gets(cc);  }
break;

// *****************************************************************
// *                              EXIT ROUTINE
// *****************************************************************

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\tThat's not Yes or No, please enter a Y or N. -- \a";
} while ((c != 'Y') || (c != 'N'));  }
if (c == 'Y') {
```

```
     clrscr();
     cout << "\n\n\n\t\tP R O G R A M   T E R M I N A T E D\n";
     exit(0); }
goto M; }

// *************************************************************
// *                          INPUT FUNCTION
// *  Enter program variables for calculations.
// *************************************************************

void input(void) {
clrscr();
cout << "\n\t\t\tWall Properties\n\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        Reenter the final elevation of the
 excavation. -- \a";
cin >> belev; }
cout << "\n\tEnter the number of anchors that are to be used to
 support the" <<  "\n\t 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 (l = 0; l < numa; ++l)  {
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\t        the top of the excavation
 and above the bottom of the excavation." << "\n\t        Reenter
 the elevation of this anchor. -- \a";
cin >> anc[j];  }
hh = anc[j];  ++j;  } }
cout << "\n\tEnter the spacing of the soldier piles. -- ";
```

```
cin >> s;
clrscr();
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\t        Please reenter soil type. -- ";
cin >> soil_type; }
clrscr();
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\t the saturated unit weight of the soil
 above and below the" << "\n\t ground water table.";
cout << "\n\n\tIf you would like to accomplish an EFFECTIVE
 STRESS ANALYSIS" << "\n\t enter the satuarted unit weight of the
 soil above the water" << "\n\t table and the buoyant unit weight
 of the soil below the water" << "\n\t table.  The water table
 elevation should be located above the" << "\n\t bottom of the
 cut.";
cout << "\n\n\tEnter 1 for a total stress analysis and 2 for an
 effective" << "\n\t stress analysis. -- ";
cin >> str_anal;
while ((str_anal <= 0) || (str_anal  >= 3)) {
cout << "\n\tERROR - Please enter either a 1 (total) or 2
 (effective). --\a";
cin >> str_anal; }
clrscr();
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"; }
```

```
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 ERROR - The location of the ground water table must
 be above the bottom" << "\n         of the excavation for an
 effective stress analysis." << "\n\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\t
 Surcharge load (ksf), width of strip load (ft),"  << "\n\t and
 the distance the strip load is from the wall  (ft)."; cout <<
 "\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\n\n\tEnter 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);
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, ffp);
fgets(project, 60, ffp);
fgets(date, 30, ffp);
fscanf(ffp, "\n %f \n %f \n %f \n %d", &telev, &belev, &s,
 &numa);
for (i = 0; i < numa; ++i)
{ fscanf(ffp, "\n %f", &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 %f %f", &soil[i][0], &soil[i][1],
 &soil[i][2]);}
fscanf(ffp, "\n %f \n %f \n %f %f %f", &b, &q, &qs[0], &qs[1],
 &qs[2]);
fclose(ffp);
cout<< "\n\tPlease reenter:  Engineer's name. -- ";
gets(engineer);
cout << "\t                  Project title. -- ";
gets(project);
cout << "\t                  Date. -- ";
gets(date);
cout << "\n\tData 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\t\tW A L L    P R O P E R T I E S\n";
printf ("\n\t1.  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\n\t    The anchors are located as follows:\n" <<
 "\t\tAnchor" << "\tElevation (feet)\n";
j = 0;
for (i = 0; i < numa; ++i)
{ printf("\t\t  %2d\t      %5.2f\n", ++j, anc[i]);}}
cout << "\n\t7.  The spacing of the soldier piles is " << s << "
 feet.";
cout << "\n\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\t\tS O I L   P R O P E R T I E S";
cout << "\n\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 ("        %7.2f        %1.4f            %5.2f",
 soil[j][0], soil[j][1], soil[j][2]);
j++; }
cout << "\n\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\n\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'); }
```

```
// ***************************************************************
// *                             EDIT DATA ROUTINE
// *  Edit program variables.
// ***************************************************************

if (c == 'Y') {
cout << "\n\tEnter the number of what you want to change -- ";
while ((i = atoi(gets(cc))) <= 0 || i >= 13)
{ cout << "\n\t" << cc << " is an incorrect response.\a";
cout << "\n\tYour choice? --"; }
clrscr();
switch (i) {
case 1: cout << "\n\tEnter the Engineer's name -- ";
     gets(engineer);
     break;
case 2: cout << "\n\tEnter the project name. -- ";
gets(project);
break;
case 3: cout << "\n\tEnter the date. -- ";
gets(date);
break;
case 4: cout << "\n\tEnter the elevation of the top of the
 excavation in feet. -- \n";
cin >> telev;
soil[0][0] = telev;
break;
case 5: cout << "\n\tEnter the elevation of the bottom of the
 excavation in feet. -- ";
cin >> belev;
break;
case 6:
cout << "\n\tEnter the number of anchors that are to be used. --
 ";
cin >> numa;
hh = 0;
if (numa != 0)
{  j = 0;
cout << "\n\tEnter 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 << "\n\tERROR- The elevation of this anchor must be below
 the prior anchor or" << "\n\t       the top of the excavation
 and above the bottom of the excavation." << "\n\n\tReenter the
 elevation of this anchor. -- \a";
cin >> anc[j]; }
hh = anc[j];  ++j;  }  }
```

```
break;
case 7:
cout << "\n\tEnter the spacing of the soldier piles. -- ";
cin >> s;
clrscr();
break;
case 8: cout << "\n\n\tEnter the elevation to the water table in
 feet. -- ";
cin >> gwt;
if (gwt > telev)  {
cout << "\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; }
break;
case 9: cout << "\n\tEnter the number of soil 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\tERROR - The soil type must be either 1 (sands) or 2
 (clays)." <<   "\n\t        Please reenter soil type. -- \a";
cin >> soil_type; }
if (soil_type == 2) {
cout << "\n\tDo you wish to perform a total or effective stress
 analysis?"      << "\n\tEnter 1 for a total stress analysis and
 2 for an effective"      << "\n\t stress analysis. -- ";
cin >> str_anal;
while ((str_anal <= 0) || (str_anal  >= 3)) {
cout << "\n\tERROR - Please enter either a 1 (total) or 2
 (effective). --\a"; cin >> str_anal; } }
cout << "\n\tEnter the soil layer's properties:" <<
 "\n\tElevation of top of the layer, unit weight, and friction
 angle"  << "\n\t or undrained shear strength.\n";
hh = 1E8;  j = 0;
for (l = 0; l < nums; ++l)  {
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;  }
```

```
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\n\t\tPlease enter 0 if none. -- ";
cin >> q;
break;
case 12:
cout << "\n\tEnter the data for any strip load:" << "\n\t
 Surcharge load (ksf), length of strip load (ft)," << "\n\t and
 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;  }
clrscr();
if (i < 8) goto WALL;
  else goto SOIL; } }

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

void save_data(void) {
FILE *fp;
clrscr();
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, "\n %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]);
fclose(fp);
cout << "\n\tData saved, press enter key to return the main
 menu.";
gets(cc);
clrscr(); }

// ****************************************************************
// *                                    ANALYSIS FUNCTION
// *  Determine soil type, call subfunction to accomplish
// *  calculations, and display results from analysis.
// ****************************************************************

void analysis(void) {
clrscr();
// Enter Width of Pile, Factor of Safety, & Excav. Depth
cout << "\n\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 --
 \a";
cin >> bf;}
if (bf == 0) bf = 1;
cout << "\n\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 << "\nERROR - Factor of safety must be positive, Reenter
 F.S. -- \a";
cin >> fs; }
if (fs == 0) fs = 1.5;
if (numa) {
```

```
cout << "\n\n\tEnter the depth in feet below the anchor location
 that is to " <<   "\n\t excavated prior to installing the
 anchor. -- " ;
cin >> w; }
clrscr();
cout <<"\n\n\n\t\t\tC A L C U L A T I N G ";
if (soil_type == 1) sand_analysis();
if (soil_type == 2) clay_analysis();
if (z[0] >= 0) {  i = 1, j = 0;
clrscr();
cout << "\n\n\tRESULTS:" << "\n\n\tEstimated width of the soldier
 pile is " << bf << " feet.";
cout << "\n\tFactor of Safety for passive resistance is " << fs
 << ".";
cout << "\n\tThe wall was excavated " << w  << " feet below the
 proposed anchor location.";
cout << "\n\n\t    STAGE    ZERO    MAXIMUM   SECTION   EMBEDMENT
 REACTION(S)"      << "\n\t                SHEAR   MOMENT    MODULUS
   DEPTH"      << "\n\t               (ft)     (k-ft)     (in^3)
 (ft)        (kips)"      << "\n\t ------------------------------
 ----------------------------------" ;
printf( "\n\t       %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( "\n\t       %d     %6.1f   %6.2f    %6.2f      %6.1f     R1 =
 %6.2f", i, z[i-1], M[i-1], S[i-1], D[i-1], R[0][j]);
for (k = 2; k <=  numa; ++k)    {
if (R[k-1][j]) {
cout << "\n\t\t\t\t\t\t\t   R" << k << " = ";
printf("%6.2f", R[k-1][j]); } }  ++j; }
printf("\n\nNOTE:  Stage 1 moment based on Kiewit criteria is
 %6.1f kip-ft.", Mk[0]);
if (numa > 0) {
printf("\n       Stage 2 moment based on Kiewit criteria is %6.1f
 kip-ft", Mk[1]);
printf("\n         and reaction force is %6.1f kips.", Rk); }
if (numa > 1) printf("\nNOTE:  Minimum depth of embedment based
 on maximum moment is %3.1f feet.", Dmin);
if ((D[numa] < 6) || (Dmin < 6)) {
cout << "\nNOTE:  NYCTA recommends minimum penetration depth of
 six feet."; }  }
if ((soil_type == 2) && (str_anal == 1))
printf ("\nNOTE:  A total stress analysis approach was used.");
if ((soil_type == 2) && (str_anal == 2))
printf ("\nNOTE:  An effective stress analysis approach was
 used.");
cout << "\n\nPress the enter key to return to the main menu.  ";
gets(cc);  }
```

```
// ************************************************************
// *                           SAND ANALYSIS FUNCTION
// *  Execute analysis for sands
// ************************************************************

void sand_analysis(void) {

// ************************************************************
// *                           STAGE I - SAND
// ************************************************************

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*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*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*v/6 + 0.0104*bf*(3*Kp/fs-Kab)*pow((v-telev+hh+gwt),3)
```

```
 > 0)      v = v + 0.05;  }
D[0] = v;
z[0] = hh + z[0];
//                          Calculate Moment based on Kiewit Analysis
Mk[0] = Ka*qe*hh*s*(hh/2+2)+Ka*wt*hh*hh*s*(hh/3+2)/2; Dmin = 7;
cout << "\n\n\t\t   S T A G E  1  C O M P L E T E D. ";

// *****************************************************************
// *                          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();
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 */ pp = (3*Kp/fs-Kab)*wtb*bf;
v = 0;
u = 0;
while (sigh + sigs + Kab*(hh*wt+qe)*bf*v - pp*v*v/2 + u > 0)  {
v = v + 0.05;
if (gwt >= (telev - hh ))  u = 0.0312*bf*(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)*bf*v - pp*v*v/2 +
0.0312*bf*(3*Kp/fs-Kab)*(v-telev+hh+gwt)*(v-telev+hh+gwt) > 0)
 v = v + 0.05; }
                    /* Reaction Force */
if (gwt <= (telev - hh - v)) { 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); }   }
R[0][0] = (sigh*(hh/3+v)+ sigs*(hh/2+v)+ Kab*(wt*hh+qe)*bf*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)*bf*v + pp*v*v*bf/2
 - u < 0 )   { v = v + 0.05;
if (gwt >= (telev - hh ))  u = 0.0312*bf*(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)*bf*v + pp*v*v*bf/2
 - 0.0312*bf*(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*(wt*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
 + pp*D[1]*D[1]/2*bf*(hh-telev+anc[0]+2*D[1]/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; }
z[1] = z[1] + hh;
//                      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\t\t   S T A G E  2  C O M P L E T E D. "; }

// ****************************************************************
// *                          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+sigs)*s/2 - v) / (anc[k]-H);
} i = 0;
// Calculate point of Zero Shear
v = R[0][j-1];
while (v - (telev - anc[i]) * (sigh + sigs) * s > 0 )
{ v = R[++i][j-1] + v;
if (i == j - 1) break;  }
z[j] = v / ((sigh + sigs) * 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 + sigs) * 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\t   S T A G E  " << j << "  C O M P L E T E D. ";
} }

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

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

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

if (numa) hh = anc[0] - w;
   else hh = belev;
float hhh = telev - hh;
wt_c_cb();   /*  Calculate Average unit wt, c, and c base */
strip();
zt = (2*ca-qe)/wt;      /*  Depth of Tension Zone  */
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[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  */
pp = (6*cb/fs+2*cb-wt*hhh-qe)*bf;  // Result. Resistance Press.
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\t\t   S T A G E  1  C O M P L E T E D. ";

// *************************************************************
// *                            STAGE II - CLAYS
// *************************************************************

if (numa) {
j = 1;
if (numa == 1) hh = belev;
   else hh = anc[1] - w;
wt_c_cb();
strip();
zt = (2*ca-qe)/wt;
if (zt > Kp) zt = Kp;
hhh = telev-hh;
```

```
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;
 Mc[1] = 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;
```

```
Rk = s*(qe-2*ca)*v + s*wt*v*v/2 +
 s*((qe-2*ca+wt*v)*y/2+wt*y*y/6); }
if (((zt >= 0) && (zt >= y)) && (zt < hhh)) {
Mk[1] = s*y*y/9 * (qe-2*ca+wt*hhh)*H/(2*y);
Rk = s*(wt*hhh+qe-2*ca)*H*H/(6*y); }
if ((zt >=0) && (zt < y)) {
Mk[1] = s*y*y/9 * (qe - 2*ca + wt*v + wt*y/2);
Rk = s*((qe-2*ca+wt*v)*(v-zt)/2 + (qe-2*ca+wt*v)*y/2 + wt*y*y/6);
} cout << "\n\t\t   S T A G E  2  C O M P L E T E D. ";  }

// ****************************************************************
// *                               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("\a\n\n\nERROR - Soil will not support the wall below 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((a-.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) /
```

```
 (anc[k]-H);   }
v = 0;                  /* Calculate point of Zero Shear */
u = 0; z[j] = 0;
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) {
z[j] = 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)  {
while (v- s*qe*z[j] -u - s*(0.25*wt*h*h+ wt*(h-0.8*z[j]) *
 (z[j]-0.75*h)) > 0)
{ z[j] = z[j] + 0.05;
if (telev-z[j] <= gwt)
u = 0.0312*s*pow((z[j] - telev + gwt),2);  } }
if (Ns > 6) {
while ( v + s*Ka*wt*h*h/8 - s*(Ka*wt*h+qe)*z[j] - u > 0)
{ 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;
D[j] = 0;                    /* Calculate Depth of Embedment */
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\t\t   S T A G E  " << j << "  C O M P L E T E D. ";}}
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-qe)*bf*Dmin*(Dmin/2+(anc[j-2]-hh))
 - sigh*s - s*qe*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[l][0]) --l;
fab = soil[l][2];
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/270) *
 cos(b*pi/180))),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+sigs)*(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]) -
```

```
 (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;  }  }

// ****************************************************************
// *                          WT_C_CB FUNCTION
// *  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; }
wt = (v + u) / (telev - hh);
ca = y / (telev - hh);
int ij, jk;    // 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]; }
cb = (y + (20 - hh + soil[ij][0]) * soil[ij][2]) / 20; }  }


// ****************************************************************
// *                          STRIP FUNCTION
// *  Transform strip load to an equivalent surcharge load and
// *   add to the surcharge load.
// ****************************************************************

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; }
```

```
// ***************************************************************
// *                         ANCHOR FUNCTION
// *  Perform analysis for wale section modulus, and bonded and
// *  unbonded length for tieback anchor.
// ***************************************************************

void anchor(void) {
clrscr();
cout << "\n\tEnter the spacing of the anchors. -- ";
cin >> d;
cout << "\n\n\tEnter the angle of the anchors. -- ";
cin >> ang;
cout << "\n\n\tSelect soil type:"
<< "\n\t  Type      Soil Description        SPT N Value"
 << "\n\n\t    1      Fine to medium sand          12 - 30"
   << "\n\t    2      Medium to coarse sand        20 - 45"
   << "\n\t    3      Sandy Gravel                    > 45"
   << "\n\n\t    4      Medium Clay                  4 - 8"
   << "\n\t    5      Medium Stiff Clay             9 - 11"
   << "\n\t    6      Stiff Clay                   12 - 15"
   << "\n\t    7      Stiff to Very Stiff Clay     16 - 20"
   << "\n\t    8      Very Stiff Clay              21 - 30"
   << "\n\t    9      Very Stiff to Hard Clay         > 30"
   << "\n\t";
while ((type = atoi(gets(cc))) <= 0 || type >= 10)
{ cout << "\n\t" << cc << " is an incorrect response.\a";
cout << "\n\tReenter 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 <<    "\n\t         OUTPUT FROM WALE AND ANCHOR ANALYSIS\n"
 << "\n\nSpacing of the anchors is " << d << " feet."      <<
 "\nThe anchors are set at an angle of " << ang << " degrees."
```

```
  << "\nThe 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
 ANCHOR        UNBONDED");
printf(  "\n    ROW        OF WALE (in^3)    CAPACITY (kips)
 LENGTH (ft)    LENGTH (ft)");
for (i = 1; i <= numa; ++i) {
printf("\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))
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\n\nPress the enter key to return to the main menu.
 ";
gets(cc); }

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

void save(void) {
FILE *xp;
clrscr();
cout << "\n\tEnter filename to save the data. -- ";
gets(filename);
while ((xp=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': 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");
fprintf (xp, "\t
 ****************************************************** \n");
fprintf (xp, "\t
 *                                                    * \n");
fprintf (xp, "\t
 *          Design of Soldier Pile and Lagging        * \n");
fprintf (xp, "\t
 *           In Accordance with NAVFAC DM-7           * \n");
fprintf (xp, "\t
 *                                                    * \n");
fprintf (xp, "\t
 ****************************************************** \n");
fprintf (xp, "\n\n\tI.  W A L L    P R O P E R T I E S\n");
fprintf (xp, "\n\t1.  Engineer:  %s", engineer);
fprintf (xp, "\n\t2.  Project:  %s", project);
fprintf (xp, "\n\t3.  Date:  %s", date);
fprintf (xp, "\n\t4.  The elevation of the top of the excavation
 is %4.2f feet.", telev);
fprintf (xp, "\n\t5.  The elevation of the bottom of the
 excavation is %4.2f feet.", belev);
fprintf (xp, "\n\t6.  The number of anchors is %d.", numa);
if (numa) {
fprintf (xp, "\n\t    The anchors are located as follows:\n");
fprintf (xp, "\t\tAnchor\tElevation (feet)\n");
j = 0;
for (i = 0; i < numa; ++i) {fprintf(xp, "\t\t  %2d\t
 %5.2f\n", ++j, anc[i]); } }
fprintf (xp, "\n\t7.  The spacing of the soldier piles is %3.2f
 feet.", s);
fprintf (xp, "\n\n\n\tII.  S O I L   P R O P E R T I E S");
fprintf (xp, "\n\n\t8.  The elevation of the water table is %6.2f
 feet.", gwt);
fprintf (xp, "\n\t9.  The soil properties are as follow:\n");
fprintf (xp, "\n\t     Soil 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\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,", qs[0], qs[1]);
fprintf (xp, "\n\t       and located %5.1f feet from the wall.",
 qs[2]);
fprintf (xp, "\n\n\n\tIII.  W A L L   A N A L Y S I S   R E S U L
 T S");
fprintf (xp, "\n\n\t13.  Estimated width of the soldier pile is
 %3.2f feet.", bf);
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\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 ---------------------------------------------
 -------------------");
fprintf (xp,  "\n\t      1    %6.1f   %6.2f    %6.2f   %6.1f
      ---",    z[0], M[0], S[0], D[0]);
j = 0;
for (i = 2; i <= numa + 1; ++i) {
fprintf (xp,  "\n\t      %d    %6.1f   %6.2f    %6.2f   %6.1f
  R1 = %6.2f", i, z[i-1], M[i-1], S[i-1], D[i-1], R[0][j]);
for (k = 2; k <=  numa; ++k)    {
if (R[k-1][j]) {
fprintf (xp, "\n\t\t\t\t\t\t\t   R%d = ", k);
fprintf (xp, "%6.2f", R[k-1][j]); } }
++j; }
fprintf(xp, "\n\n  NOTE:  Stage 1 moment based on Kiewit criteria
 is %6.1f kip-ft.", Mk[0]);
if (numa > 0) {
fprintf(xp, "\n         Stage 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:  An effective stress analysis approach
 was used.");
if (bp > 2) {
fprintf (xp, "\n\n\n\tIV.  A N C H O R   A N D   W A L E   R E S
 U L T S");
fprintf (xp, "\n\n\t17.  Spacing of the anchors is %3.1f feet.",
 d);
fprintf (xp, "\n\t18.  The anchors are set at an angle of %3.1f
 degrees.", ang);
fprintf (xp, "\n\t19.  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\t20.\n");
fprintf (xp, "\n  ANCHOR    SECTION MODULUS        ANCHOR
 ANCHOR        UNBONDED");
fprintf (xp, "\n   ROW        OF WALE (in^3)    CAPACITY (kips)
 LENGTH (ft)    LENGTH (ft)");
fprintf (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          effective grout pressure in excess of
 150 psi with a diameter");
fprintf (xp,   "\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    O 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:

$$K_a = \tan^2(45 - \phi/2) \quad \text{- LEVEL BACKFILL}$$

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

FOR SLOPED BACKFILL WHERE,

ϕ - FRICTION ANGLE

θ - INCLINATION OF WALL

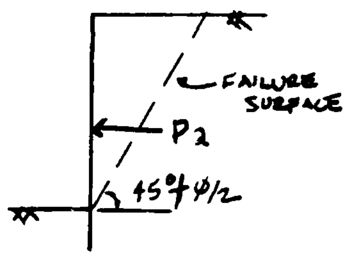
β - SLOPE OF BACKFILL

δ - FRICTION ANGLE BETWEEN PILE & SOIL

SETTING $\theta = 0°$ AND $\delta = 2/3\,\phi$, Ka CAN BE REDUCED TO

$$K_a = \frac{\cos^2\phi}{\cos(2\phi/3)\left[1 + \sqrt{\sin(5\phi/3)\sin(\phi-\beta)/\cos(2\phi/3)\cos\beta}\right]^2}$$

FAILURE SURFACE = $45° + \phi/2$



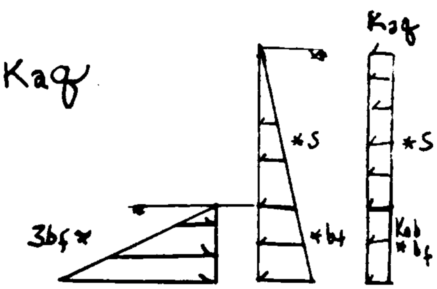
$$K_p = \tan^2(45 + \phi/2)$$

THEREFORE,

$$\sigma_a = K_a \gamma Z \quad \& \quad P_a = K_a \gamma H^2/2 \quad P_q = K_a q$$

$$\sigma_p = K_p \gamma Z$$

PASSIVE RESISTANCE ACTS ON 3bf



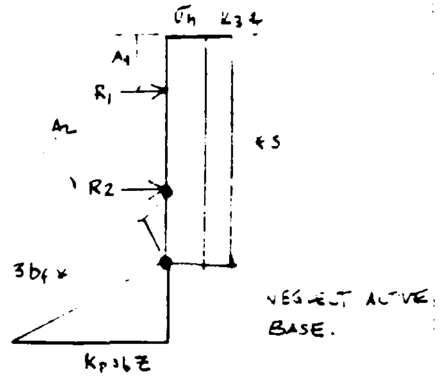
STAGE I:

ZERO SHEAR: $\Sigma V = \emptyset = K_a \gamma H_1^2/2 * S + K_a q H_1 * S + K_{ab}(\gamma H_1 + q) b_f Z - (3K_p/f_s - K_{ab})\gamma_b b_f Z^2/2$

SOLVE FOR Z.

MAX MOMENT, $\Sigma M_Z = K_a \gamma H_1^2/2 * S(H_1/3 + Z) + K_a q H_1 * S(H_1/2 + Z) + K_{ab}(\gamma H_1 + q) b_f Z^2/2 - (3K_p/f_s - K_{ab})\gamma_b b_f Z^3/6$

STAGE III: 2 OR MORE ANCHORS.



$\sigma_h = 0.65\, K_a \gamma H_3$

REACTION FORCES—

$\Sigma M_{R2} = R1*(A2-A1) - (\sigma_h + K_a q) S A2^2/2 = \emptyset$

$R_1 = [S(\sigma_h + K_a q) A2^2]/2(A2-A1)$

SIMILARY, $R2 = [S(\sigma_h + K_a q) H3^2/2 - R_1(H3-A1)]/(H3-A_2)$

OR

$$R_i = \left[S(\sigma_h + K_a q) A_{i+1}^2/2 - \sum_{j=1}^{i-1} R_j (A_{i+1} - A_j)\right] / (A_{i+1} - A_i)$$

ZERO SHEAR, $\Sigma V = 0 = R_1 + R_2 - (\sigma_h + qK_a) S Z$

OR $Z = (R_1 + R_2)/(\sigma_h + qK_a) S$

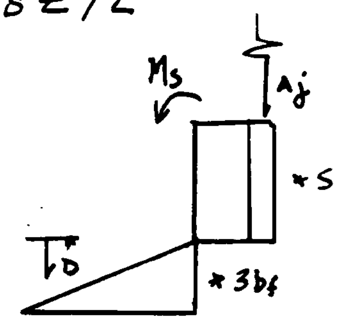
OR

$$Z = \sum_{i=1}^{j} R_i / (\sigma_h + qK_a) S$$

MAX MOMENT, $\Sigma M_Z = R_1(Z - A_1) + R_2(Z - A_2) - (\sigma_h + K_a q) S Z^2/2$

OR $M = \sum_{i=1}^{j} R_i (Z - A_i) - (\sigma_h + K_a q) S Z^2/2$

DEPTH OF EMBEDMENT, D



$\Sigma M_j = 0 = M_s + 3K_p/f_s\, b(\gamma_b D^2/2) * (2D/3 + H_3 - A_j)$
$- (\sigma_h + qK_a) S (H_3 - A_j)^2/2.$

SOLVE FOR D.

DEPTH OF EMBEDMENT: $\Sigma M_D = \emptyset$

$$\Sigma M_D = P_A (H_1/3 + D) * S + P_q (H_1/2 + D) * S + K_{ab}(\gamma H_1 + q) b_f D^2/2 - (3K_p/fs - K_{ab}) b_f \gamma_b D^3/6 = \emptyset$$

SOLVE FOR D.

STAGE II: 1 STRUT

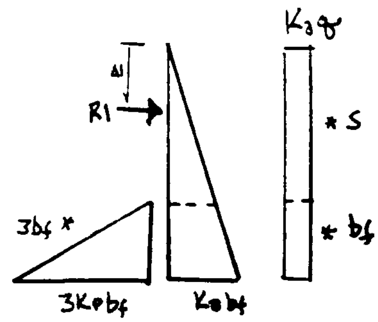
POINT OF ZERO NET FORCE ON EMBEDDED PILE AND ASSUME HINGED AT THAT POINT (ZERO MOMENT).

$$\Sigma F_y = 0 = P_A * S + P_q * S + K_{ab} b_f * (q + H_2 \gamma) X - (3K_p/fs - K_{ab}) b_f \gamma_b X^2/2$$

SOLVE FOR X.

REACTION FORCE:

$$R_1 = [P_A * S (H_2/3 + X) + P_q * S (H_2/2 + X) + K_a b_f (q + H_2 \gamma) X^2/2 - (3K_p/fs - K_{ab}) * b_f \gamma_b X^3/6] / (H_2 - A_1 + X)$$

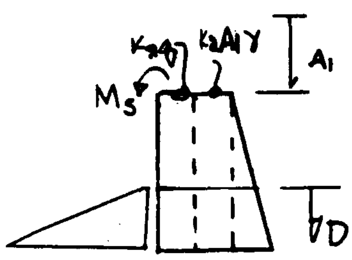


ZERO SHEAR, $\Sigma V = 0 = R_1 - P_a - P_q - K_{ab}(q + H_2 \gamma) b_f Z + (3K_p - K_a) b_f \gamma_b Z^2/2$

SOLVE FOR Z.

MAX. MOMENT, $\Sigma M_Z = R_1 (H_1 - A_1 + Z) + (3K_p - K_{ab}) b_f \gamma_b Z^3/6 - P_A (H_2/3 + Z) - P_q (H_2/2 + Z) - K_{ab}(q + H_2 \gamma) b_f Z^2/2$

DEPTH OF EMBEDMENT:



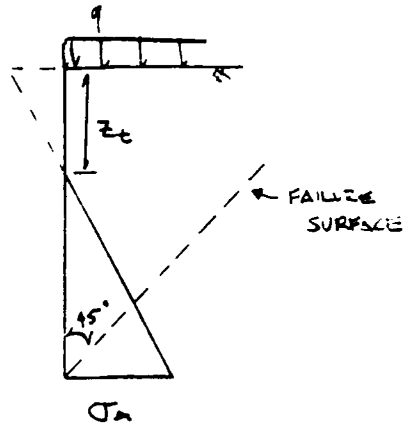
$$\Sigma M_A = M_S + (3K_p - K_a) b_f \gamma_b Z^2/2 (H_2 - A_1 + 2D/3) - K_a (q + A_1 \gamma)(H_2 - A_1)^2 * S/2 - K_a S \gamma (H_2 - A_1)^3/3 - K_{ab}(q + H_2 \gamma) * D(D/2 + H_2 - A_1) b_f = \emptyset$$

SOLVE FOR D.

REQUIRED SECTION MODULUS, $S = M/\sigma_y = \frac{M * 12}{0.8 * 36}$

$S = M/2.4$ (IN^3), WHERE M IN K.FT.

CLAYS:



HEIGHT OF TENSION ZONE,

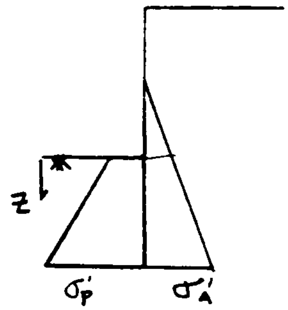
$z_t = (2c - q)/\gamma$

WHERE $2c > q$

ELSE $z_t = \emptyset$.

$\sigma_A = \gamma z - 2c + q$

$\sigma_p = \gamma z + 2c$



NET PASSIVE RESISTANCE BELOW BOTTOM OF CUT:

DM-7 → UNIFORM RESISTANCE OF $2c * 3b_f$ WITH FACTOR OF SAFETY (fs)

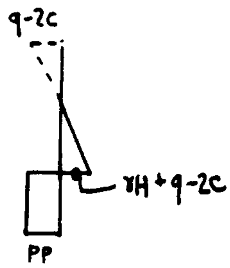
$\sigma_p' = 6c \cdot b_f / fs$

$\sigma_a' = (q + \gamma H - 2c) * b_f$

NEGLECT SOIL RESISTANCE (γz)

NET $pp = \sigma_p' - \sigma_A' = (6c/fs + 2c - q - H\gamma) * b_f$

IF $6c/fs + 2c < q + H\gamma$, SOIL WILL NOT SUPPORT THE WALL.



STAGE I: NEGLECT TENSION ZONE

IF $z_t > A1 \longrightarrow \sigma = \emptyset$

IF $z_t < A1 \longrightarrow \sigma_a = \gamma H + q - 2c$

ZERO SHEAR, $V = 0 = \sigma_A * (H_1 - z_t)/2 * S - pp\, z$

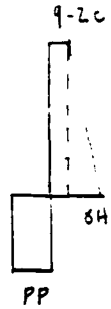
$z = \sigma_A * (H_1 - z_t) S / 2\, pp$

MAX MOMENT, $\Sigma M_Z = \sigma_A * (H_1 - Z_t)/2 * S * (\frac{H_1 - Z_t}{3} + Z) - pp * Z^2/2$

DEPTH OF EMBEDMENT, D

$$\Sigma M_D = 0 = \sigma_A (H_1 - Z_t) * S/2 * (\frac{H_1 - Z_t}{3} + D) - pp * D^2/2$$

SOLVE FOR D.



IF $Z_t < 0 \rightarrow$ NO TENSION ZONE

ZERO SHEAR, $\Sigma V = 0 = (q-2c)H_1 S + \gamma H^2 S/2 - pp * Z$

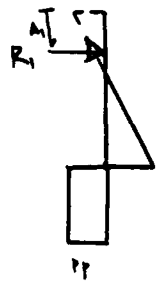
$$Z = [(q-2c)H_1 S + \gamma H^2 S/2]/pp$$

MAX MOMENT, $\Sigma M_Z = (q-2c)H_1 S (H_1/2 + Z) + \gamma H_1^2/2 * S (H_1/3 + Z) - pp\ Z^2/2$

DEPTH OF EMBEDMENT, $\Sigma M_D = 0$

$$S(q-2c)H_1(\frac{H_1}{2} + D) + \gamma H_1^2/2 * S(H_1/3 + D) - pp\ D^2/2 = \emptyset$$

SOLVE FOR D.



STAGE II: $Z_t > 0$ BUT $Z_t <$ CUT BOTTOM

NET ZERO FORCES ON EMBEDDED PILE, $\Sigma F_y = 0$

$$S(\gamma H_2 + q - 2c)(H_2 - Z_t)/2 - pp * X = 0$$

$$X = S(\gamma H_2 + q - 2c)(H_2 - Z_t)/2pp$$

REACTION FORCE, $R_1 \rightarrow \Sigma M_X$

$$S(\gamma H_2 + q - 2c)(H_2 - Z_t)/2 * (\frac{H_2 - Z_t}{3} + X) - pp * X^2/2 - R_1 * (H_2 - A1 + X) = \emptyset$$

POINT OF ZERO SHEAR

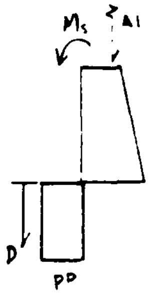
$$\Sigma V = 0 = S(\gamma H_2 + q - 2c)(H_2 - Z_t)/2 - pp * Z - R_1$$

$$Z = [S(\gamma H_2 + q - 2c)(H_2 - Z_t)/2 - R_1]/pp$$

MAX. MOMENT, $\Sigma M_Z = S(\gamma H_2 + q - 2c)(H_2 - Z_t)/2 * \left(\frac{H_2 - Z_t}{3} + Z\right)$
$- pp * Z^2/2 - R1 * (H_2 - A1 + Z)$

DEPTH OF EMBEDMENT

$\Sigma M_{A1} = \emptyset = M_S + pp * D * (D/2 + H_2 - A1) -$
$S * (q - 2c + \gamma A1) * (H_2 - A1)^2/2 -$
$2S * \gamma (H_2 - A1)^3/6 .$

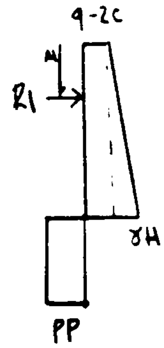


SOLVE FOR D.

$Z_t < \emptyset$

NET ZERO FORCES, $\Sigma F_y = S(\gamma H^2/2) + S(q - 2c)H - pp * X = \emptyset$.

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



REACTION FORCE, $\Sigma M_x = \emptyset$.

$R1 = [S\gamma H_2^2/2(H_2/3 + X) + S(q - 2c)H_2(H_2/2 + X) - pp X^2/2]/(H_2 - A1 + X)$

PT. OF ZERO SHEAR, $\Sigma V = \emptyset$

$Z = [S \gamma H_2^2/2 + S(q - 2c)H_2 - R_1]/pp$

MAX. MOMENT, $\Sigma M_Z = S\gamma H_2^2/2 * (H_2/3 + Z) + S(q - 2c)H_2(H_2/2 + Z)$
$- pp * Z^2/2 - R1(H_2 - A1 + Z)$

DEPTH OF EMBEDMENT, SAME AS $Z_t > \emptyset$ FOR STAGE II.

STAGE III :

STABILITY NUMBER, $N_s = \gamma H_i / c$

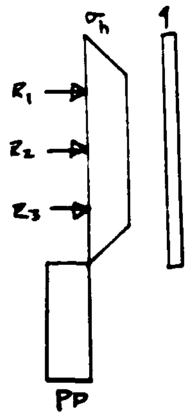
CASE A: IF $N_s \leq 4 \rightarrow$ $\sigma_h = 1.6\gamma Z$ WHERE $Z < 0.25H$
$\sigma_h = 0.4\gamma H$ WHERE $H/4 \leq Z \leq 3H/4$
$\sigma_h = 1.6\gamma(H - Z)$ WHERE $Z > 3H/4$

CASE B: IF $N_s > 6 \longrightarrow$ $\sigma_h = 4K_a\gamma Z$ WHERE $Z < H/4$
$\sigma_h = K_a\gamma H$ WHERE $Z \geq H/4$
$K_a = 1 - 4mC/\gamma H$ WHERE $m = 1.$

IF $N_s > 4$ BUT $N_s \leq 6 \longrightarrow$ USE LARGER OF TWO STRESSES.

REACTION FORCE:

$$R_i = [S * \Sigma \sigma_h * A_s * \bar{X} + Sq A_{i+1}^2/2 - R_{i-1} * (A_{i+1} - A_{i-1})] / (A_{i+1} - A_i)$$



LOCATION OF ANCHOR — STRESS CASE A

$A_i < H/4$ $\Sigma\sigma_s A_s \bar{X} = 1.6\gamma(A_{i+1}^3)/6$

$H/4 \leq A_i < 3H/4$ $= 0.05\gamma H^2(A_{i+1} - H/6) + 0.2\gamma H(A_{i+1} - H/4)^2$

$A_i \geq 3H/4$ $= 0.05\gamma H^2(A_{i+1} - H/6) + 0.2\gamma H^2(A_{i+1} - H/2) +$
$0.4\gamma(A_{i+1} - 0.75H)^2(H - 2/3 A_{i+1})$

STRESS CASE B

$A_i < H/4$ $\Sigma\sigma_s A_s \bar{X} = 2K_a\gamma A_{i+1}^3/3$

$A_i \geq H/4$ $= K_a\gamma H^2/8 * (A_{i+1} - H/6) + K_a\gamma H * A_{i+1} * (A_{i+1} - H/4)/2$

ZERO SHEAR: $\Sigma V = 0$

CASE A:

$V = \Sigma R_i - S * (0.05\gamma H^2 + 0.4\gamma H(Z - H/4)) - Sq Z = \emptyset$ WHERE $Z \leq 3H/4$

OR

$V = \Sigma R_i - S * (0.25\gamma H^2 + \gamma(H - 0.8Z) * (Z - 0.75H)) - S * q Z = 0$
WHERE $Z > 3H/4$

ZERO SHEAR – CASE B:

$$V = \Sigma R_i - S[K_a \gamma H^2/8 + K_a \gamma H(Z - H/4)] - S * q Z = \emptyset$$

MAX. MOMENT $\Sigma M_Z = M_{MAX}$

CASE A → $Z \leq 3H/4$:

$$\Sigma M_Z = \Sigma R_i * (Z - A_i) - S * q Z^2/2 - S * [0.05 \gamma H^2 * (Z - H/6) + 0.2 \gamma H^2 (Z - H/2)]$$

$Z > 3H/4$:

$$\Sigma M_Z = \Sigma R_i * (Z - A_i) - S * q Z^2/2 - S * [0.05 \gamma H^2 * (Z - H/6) + 0.2 \gamma H^2 (Z - H/2) + 0.4 \gamma (Z - 0.75H)^2 (H - 2Z/3)]$$

CASE B

$$\Sigma M_Z = \Sigma R_i * (Z - A_i) - S q Z^2/2 - S * [K_a \gamma H^2/8 * (Z - H/6) + K_a \gamma H Z (Z - H/4)/2]$$

DEPTH OF EMBEDMENT

$$PP = (6c/f_s + 2c - q) b_f * D * (D/2 + H - A_j)$$ NEGLECT SOIL PRESSURE BELOW CUT.

CASE A, $A_j \leq 3H/4$:

$$\Sigma M_{A_j} = M_s + PP - S * [0.4 \gamma H * (0.75H - A_j) + 0.05 \gamma H^2 (5H/6 - A_j)] = \emptyset$$

$A_j > 3H/4$:

$$\Sigma M_{A_j} = M_s + PP - S * [0.8 \gamma (H - A_j)^3/3] = \emptyset$$

CASE B

$$\Sigma M_{A_j} = M_s + PP - S * [K_a \gamma H * (H - A_j)^2/2] = \emptyset$$

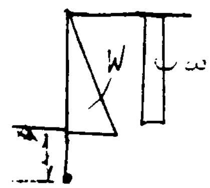
SOLVE FOR D.

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.



ASSUME PINNED 2-3' BELOW BTM OF CUT.

SANDS: (USE 2 FT)

$$M_{K1} = K_a S\left[q H_t (H/2+2) + \gamma H^2/2 (H/3+2)\right]$$

CLAYS:

IF $Z_t < \phi \rightarrow M_{K1} = S\gamma H^2/2 \,(H/3+2) + S(q_e - 2c)h\,(h/2+2)$

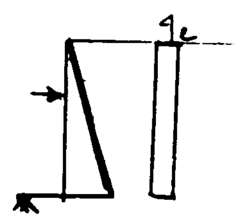
IF $Z_t > 0 \rightarrow M_{K1} = S(\gamma H + q_e - 2c)(H - Z_t)/2 * ((H - Z_t)/3 + 2)$

STAGE II

MAX. MOMENT, $M_{max} = w\,l^2/9 * S$

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:

$$M_{K2} = S * [\,q_e + \gamma A_1 + (H - A_1)\gamma/2\,] * (H - A_1)^2/9$$

KIEWIT CRITERIA (CONTINUED)

CLAYS

IF $Z_0 < 0 \rightarrow M_{K2} = S * [q_e - 2c + \gamma A_1 + \gamma (H - A_1)/2](H - A_1)^2/9$

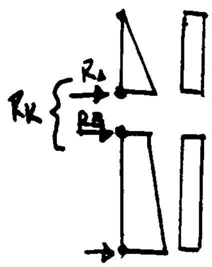
IF $Z_t \geq 0$ & $Z_t \geq A_1 \rightarrow$

$M_{K2} = S * [(q_e - 2c + \gamma H) * (H - Z_t)/(2 * (H - A_1))] * (H - A_1)^2/9$

IF $Z_t \geq 0$ & $Z_t < A_1 \rightarrow$

$M_{K2} = S * [(q_e - 2c + \gamma A_1) + \gamma (H - A_1)/2] * (H - A_1)^2/9$

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



SANDS:

$R_A = K_a S * [q A_1 + \gamma A_1^2/2]$

$R_B = K_a S * [(H - A_1)^2/2 * (q_e - \gamma A_1) + (H - A_1)^3 * \gamma/6]/(H - A_1)$

$R_K = R_A + R_B$

CLAYS

IF $Z_t < 0 \rightarrow R_K = S * [(q_e - 2c)A_1 + \gamma A_1^2/2 + (q_e - 2c + \gamma A_1)(H - A_1)/2 + \gamma (H - A_1)^2/6]$

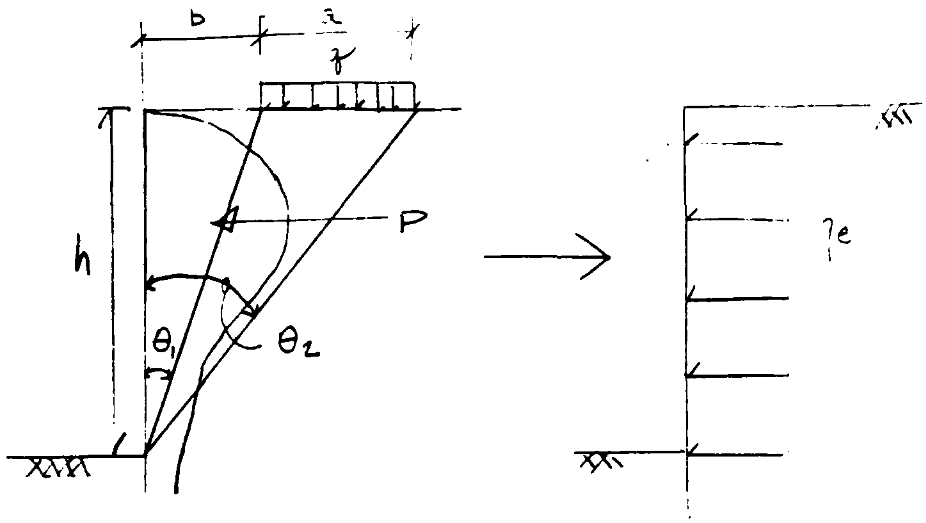
IF $Z_t \geq 0$ & $Z_t \geq A_1 \rightarrow$

$R_K = S * [(q_e - 2c + \gamma H) * (H - Z_t)^2/6]/(H - A_1)$

IF $Z_t > 0$ & $Z_t < A_1 \longrightarrow$

$R_K = S * [(q_e - 2c + \gamma A_1)(A_1 - Z_t)/2 + (q_e - 2c + \gamma A_1)(H - A_1)/2 + \gamma (H - A_1)^2/6]$

STRIP LOADS



CONVERT STRIP LOAD PRESSURE TO UNIFORM PRESSURE.

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

WHERE $\theta_2 = TAN^{-1}(a+b/h)$ (RADIANS)

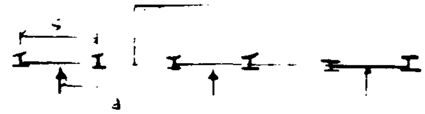
$\theta_1 = TAN^{-1}(b/h)$ (RADIANS)

$$q_e = P/h$$

$$\therefore q_e = 2q/\pi * (\theta_2 - \theta_1).$$

WALE ANALYSIS:

COVERAGE = d/s



S – SPACING OF PILES
d – SPACING OF ANCHORS

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

$\omega l = R_i * d/s$

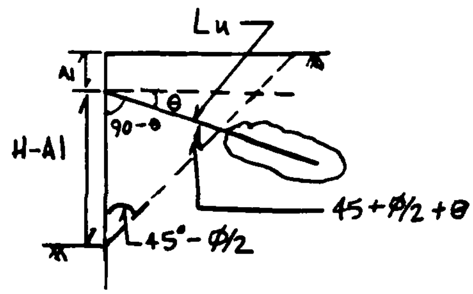
INCREASE R_i BY 33% TO ACCOUNT FOR PRELOADING TEST.

$M = 1.33 * R_i * d/s * d/8$

$S_w = M/\sigma_{ALL}$, $\sigma_{ALL} = 0.8 * 36$ KSI $= 28.8$ KSI

$\therefore S_w = 1.33 R_i d^2/8s/28.8 \longrightarrow S_w = R_i d^2/14.4S$

UNBONDED LENGTH:



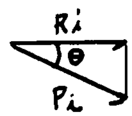
LAW OF SINES:

$$\frac{Lu}{\sin(45-\phi/2)} = \frac{H-Al}{\sin(45+\phi/2+\theta)}$$

$$Lu = (H-Al) * \frac{\sin(45-\phi/2)}{\sin(45+\phi/2+\theta)}$$

REQUIRED CAPACITY OF ANCHOR:

$P_i = R_i / \cos\theta * (d/s)$



BONDED LENGTH:

FINE TO MEDIUM SAND: $L = 10^{(P_i + 68.9)/147.0}$ (FIGURE C.1)

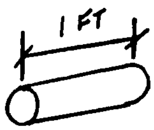
MED. - COARSE SAND: $L = 10^{(P_i + 74.5)/132.9}$ (FIGURE C.2)

SANDY - GRAVEL: $L = 10^{(P_i + 144.2)/273.2}$ (FIGURE C.3)

DEPTH OF OVERBURDEN 7/13'
DIAMETER ~ 4" - 6"

CLAYS:

CLAY CONSISTENCY	ULT. ANCHOR FRICTION (KIP/FT²)	ULT. ANCHOR CAPACITY (KIP/LF)
V. STIFF - HARD	7	11.00
V. STIFF	6	9.42
STIFF - V. STIFF	5	7.85
STIFF	4	6.28
MED. STIFF	3	4.71
MEDIUM	2	3.14



FRICTION AREA = $\pi D * 1/LF$

ASSUME $D = 6" = 1/2$ FT

FRICTION AREA = $\pi/2$ /LF

ULT ANCHOR FRICTION $* \pi/2$ = ULT. ANCHOR CAPACITY

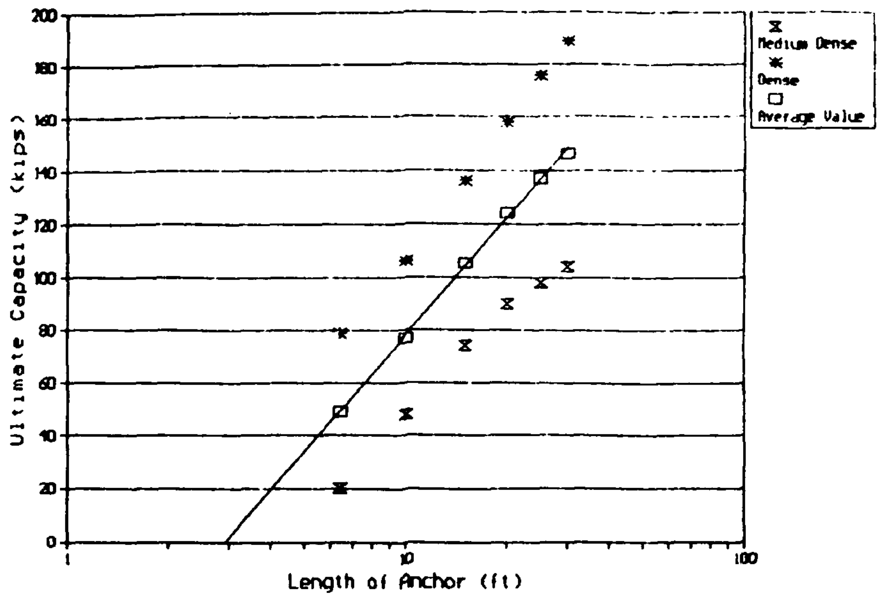


Figure C.1
Average Load Capacity of Anchors in Fine to Medium Sands

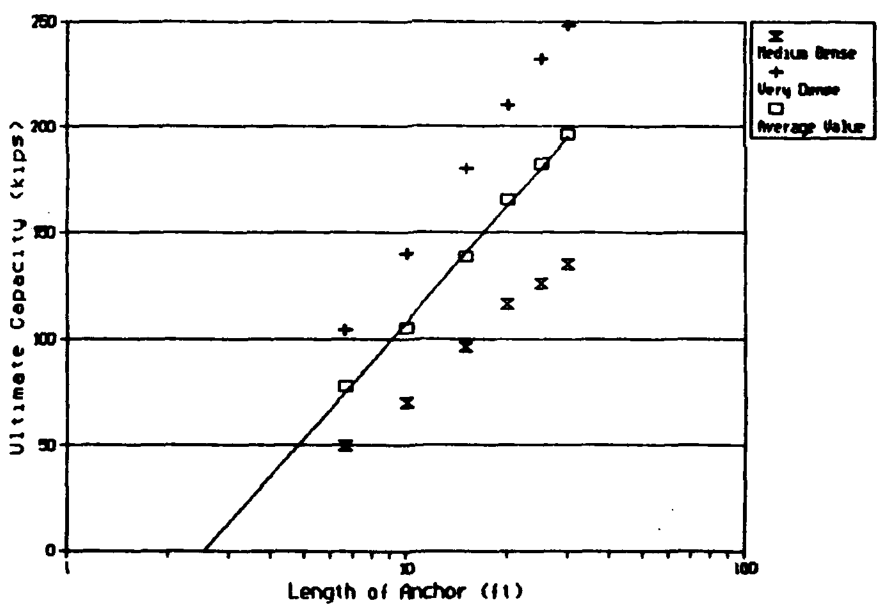


Figure C.2
Average Load Capacity of Anchors in Medium To Coarse Sands

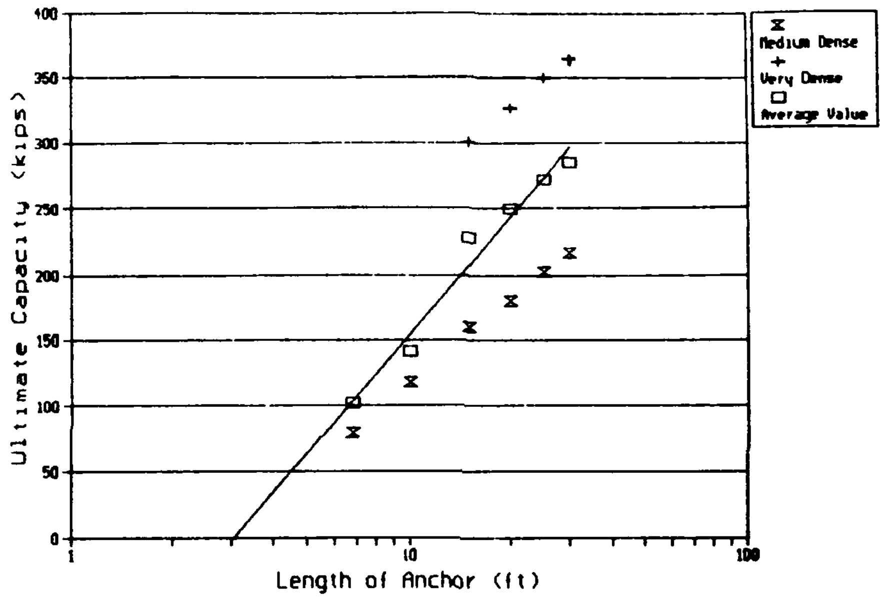


Figure C.3
Average Load Capacity of Anchors in Sandy Gravel

APPENDIX D

EXAMPLE PROBLEMS

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

I. W A L L   P R O P E R T I E S

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:

Anchor	Elevation (feet)
1	245.00
2	235.00
3	225.00

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

II. S O I L   P R O P E R T I E S

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

Soil Type	Elev	Unit Wt	Friction Angle or Cohesion
sand	250.00	0.1100	30.00

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. W A L L   A N A L Y S I S   R E S U L T S

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

STAGE	ZERO SHEAR (ft)	MAXIMUM MOMENT (k-ft)	SECTION MODULUS (in^3)	EMBEDMENT DEPTH (ft)	REACTION(S) (kips)
1	11.0	57.53	23.97	9.5	---
2	22.9	59.63	24.84	5.8	R1 = 31.24
3	20.5	71.43	29.76	5.4	R1 = 53.13
					R2 = 43.68
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 ROW	SECTION MODULUS OF WALE (in^3)	ANCHOR CAPACITY (kips)	ANCHOR LENGTH (ft)	UNBONDED LENGTH (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

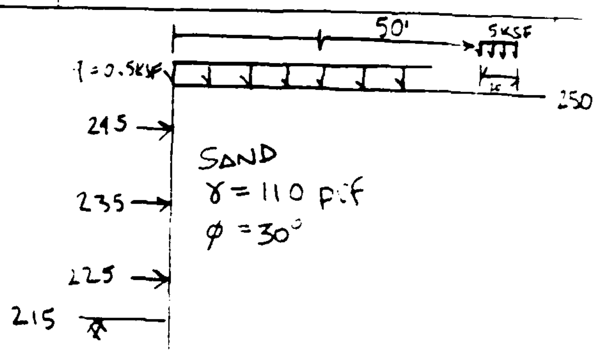
NOTE: Tieback capacity is based on pressure injected anchors using an effective grout pressure in excess of 150 psi with a diameter between 4 to 6 inches and depth of overburden greater than 13 feet.

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

END OF ANALYSIS

SAND PROBLEM #1

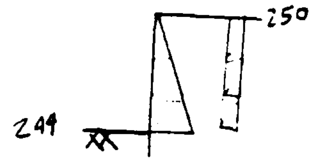
- SPACING 4 FT O.C.
- NO GWT
- ESTIMATED WIDTH OF SOLDIER PILE IS 1 FT
- FACTOR OF SAFETY VS PASSIVE RESISTANCE = 1
- OVEREXCAVATE BELOW ANCHOR 1 FT.



STAGE I

$K_a = \tan^2(45-\phi/2) = \tan^2(45-30/2)$
$= 1/3$

$K_p = \tan^2(45+\phi/2) = \tan^2(45+30/2)$
$= 3$



STRIP LOAD — CONVERT TO EQUIVILANT SURCHARGE LOAD.

$P = 2q/\pi\,(\theta_2-\theta_1)*H$

$q_e = P/K_aH = 2q/K_a\pi*(\theta_2-\theta_1) \rightarrow \theta_2 = \tan^{-1}(50+20/6) = 1.485$

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

$q_e = 2*5/\pi*(1.485-1.451)/\tfrac{1}{3}$

$q_e = 0.324$ KSF   ADD SURCHARGE LOAD $+0.5$ KSF

$q_e = 0.824$ KSF

FORCE - SOIL, $P_a = K_a\gamma H^2/2 * S = 1/3*0.11*6^2/2*4$
$= 2.64$ K

FORCE - SURCHARGE, $P_q = K_a q_e H*S = 1/3*0.824*6*4$
$= 6.592$ K

PT OF ZERO SHEAR

$\Sigma V = 0 = P_a + P_a + K_a(\gamma H + q_e)b_f Z - (3K_p/fs - K_a)b_f\gamma Z^2/2$

$= 2.64 + 6.592 + \tfrac{1}{3}(0.11*6+0.824)1(Z) - (3*3-\tfrac{1}{3})(0.11)(1)Z^2/2$

$Z = 4.95' + 6 = 10.95$ FT   (USE $Z = 5'$)

MAX. MOMENT

$$\Sigma M_z = P_a\,(H/3 + z) + P_q\,(H/2 + z) + K_a(\gamma H + q_e)\,b_f\,z^2/2 - (3K_p/FS - K_a)\,b_f\,\gamma\,z^3/6$$

$$= 2.64(6/3 + 5) + 6.592(6/2 + 5) + 0.495(5)^2/2 - 0.477 * 5^3/3$$

$$= 57.53 \text{ K}\cdot\text{ft}$$

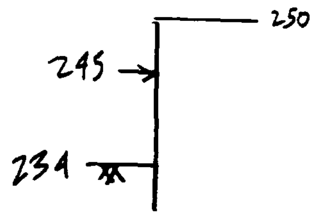
DEPTH OF EMBEDMENT

$$\Sigma M_D = 0 = P_a(H/3 + D) + P_q(H/2 + D) + K_a(\gamma H + q_e)\,b_f\,D^2/2 - (3K_p/FS - K_a)\,b_f\,\gamma\,D^3/6$$

$$= 2.64(2 + D) + 6.592(3 + D) + 0.495D^2/2 - 0.477D^3/3$$

$$D = 9.46 \text{ ft}$$

STAGE II



STRIP LOAD:

$\theta_2 = 1.346$ & $\theta_1 = 1.261$

$q_e = 10/\pi\,(1.346 - 1.261)/1/3 + q$

$q_e = 0.812 \text{ ksf} + 0.5 = 1.312 \text{ ksf}$

PT OF ZERO FORCES ON EMBEDDED PILE

$P_a = 1/3 * 0.11 * 16^2/2 * 4 = 18.773 \text{ K}$

$P_q = 1/3 * 1.312 * 16 * 4 = 27.989 \text{ K}$

$pp = (3K_p/FS - K_a)\,b_f\,\gamma = (3*3 - 1/3)*1*0.11$

$= 0.953 \text{ ksf}$

$$\Sigma F_y = P_a + P_q + K_a(\gamma H + q_e)\,b_f\,x - pp\,x^2/2 = 0$$

$$= 18.773 + 27.989 + 1/3(1.312 + 16*0.11)\,x - 0.953\,x^2/2$$

$x = 11.04 \text{ ft}$ Say $x = 11 \text{ ft}$

REACTION FORCE

ASSUME HINGED AT x (ZERO MOMENT)

$$\Sigma M_x = 0 = P_3(H/3 + x) + P_q(H/2 + x) + K_3(\gamma H + q_e) b_f x^2/2 - PP\, x^3/6 - (H - A_1 + x)R_1$$

$$= 18.733(16/3 + 11) + 27.989(16/2 + 11) + 1.024(11)^2/2 - 0.477(11)^3/3 - (16 - 5 + 11)R_1 = 0$$

$R_1 = 31.27$ K ✓

ZERO SHEAR

$$\Sigma V = 0 = 18.733 + 27.989 + 1.024Z - 0.477Z^2 - 31.27$$

$Z = 6.9$ FT $+ 16 = 22.9$ FT ✓

MAX. MOMENT

$$\Sigma M_Z = 18.733(16/3 + 6.9) + 27.989(16/2 + 6.9) + 1.024(6.9)^2/2 - 0.477(6.9)^3/3 - 31.27(11 + 6.9)$$

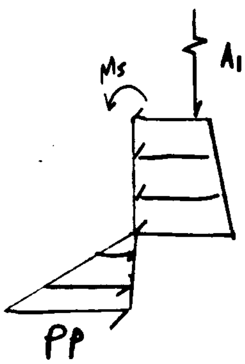
$= 58.61$ K·FT

SECTION MODULUS, $S = M_{max}/2.4 = 58.61/2.4$
$= 24.42\ in^3$ ✓

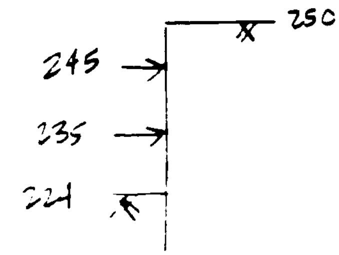
DEPTH OF EMBEDMENT

$$\Sigma M_{R1} = 58.61 + 0.477D^2(11 + 2/3D) - 1/3(1.312 + 5*0.11)*(4/2)*11^2 - 4(1/3)(0.11)11^3/3 - 1/3(1.312 + 16*0.11)* D(D/2 + 11) = 0$$

$D = 5.8$ FT ✓



STAGE III



STRIP LOAD → $\theta_2 = 1.215$ & $\theta_1 = 1.091$

$q_e = 10/\pi\,(1.215 - 1.091)/1/3 + 0.5$

$q_e = 1.682$ KSF

$\sigma_{SOIL} = 0.65\,K_a\,\gamma\,H * S = 0.65(1/3)(0.11)*26*4$

$= 2.478$

$\sigma_H = \sigma_{SOIL} + \sigma_q = 2.478 + 1.682*1/3*4 = 4.72$ KSF

REACTIONS

$\Sigma M_{R2} = \sigma_H * A_2^2/2 - R_1*(A_2 - A_1) = 0$

$= 4.72*15^2/2 - 10R_1 \longrightarrow R_1 = 53.11$ K ✓

$\Sigma M_{BASE} = \sigma_H * H^2/2 - R_1*(H - A_1) - R_2(H - A_2)$

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

$R_2 = 43.64$ K ✓

ZERO SHEAR

$\Sigma V = 0 = 53.11 + 43.64 - 4.72\,Z$

$Z = 20.5$ FT ✓

MAX MOMENT

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

$= 71.435$ K·ft

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

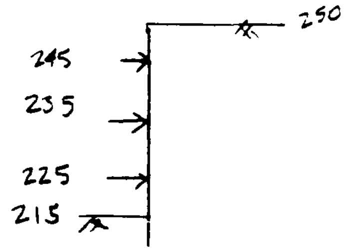
$= 29.76$ IN^3 ✓

EMBEDMENT DEPTH

$$\Sigma M_{R2} = 71.435 + 3*3*0.11D^2/2\,(2/3D+11) - 4.72*11^2/2$$

$$D = 5.43\ FT$$

STAGE IV



STRIP LOAD:

$\theta_2 = 1.107$ & $\theta_1 = 0.960$

$q_{STRIP} = 10/\pi * (1.107 - 0.960)/1/3 = 1.404$ KSF

$q_e = 1.404 + 0.5 = 1.904$ KSF

$\sigma_{SOIL} = 0.65(1/3)(0.11)(35)*4 = 3.337$ KSF

$\sigma_H = 3.337 + 1.904/3 * 4 = 5.875$ KSF

REACTION FORCES

$\Sigma M_{R2} = 5.875 * 15^2/2 - 10R_1 = \emptyset$

$R_1 = 66.09$ K

$\Sigma M_{R3} = 5.875 * 25^2/2 - 20*66.09 - 10R_2 = 0$

$R_2 = 51.41$ K

$\Sigma M_{BASE} = 5.875 * 35^2/2 - 30*66.09 - 20*51.41 - 10R_3 = \emptyset$

$R_3 = 58.75$ K

ZERO SHEAR

$\Sigma V = 0 = 66.09 + 51.41 + 58.75 - 5.875 Z$

$Z = 30$ FT

MAX MOMENT

$\Sigma M_Z = 66.09*25 + 51.41*15 + 58.75*5 - 5.875*30^2/2$

$M_{MAX} = 73.4$ K·FT $\qquad S = 30.58$ IN³

EMBEDMENT DEPTH

$\Sigma M_{23} = 73.41 + 9(0.11)D^2/2(2/3D+10) - 5.875(10)^2/2 = 0$

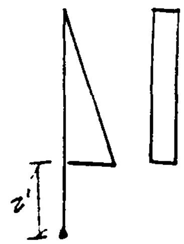
$D^2(2/3D+10) - 445.15 = 0 \longrightarrow D = 5.68$ FT

BASED ON MMAX FOR THE 4 STAGES, DMIN = 5.68 FT

BUT USE D = 6 FT

KIEWIT CRITERIA

STAGE I –



$M_{MAX} = 2.64 * (6/3+2) + 6.592(6/2+2)$

$= 43.5$ K·FT ✓

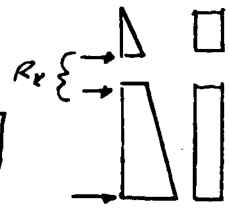
STAGE II –

$M_{MAX} = w l^2/9$

$w = [(1/3 * 0.11 * 5 + 1.312/3) * 4 * 11 + 4/3 * 0.11(11)^2/2]/11$

$= 3.289$ KSF

$M_{MAX} = 3.289 * 11^2/9 = 44.22$ K·FT



$R_K = [(1/3 * 0.11 * 5^2/2 + 1.312/3 * 5)4 + (27.3 * 1/2 + 4/3(0.11)11^3/6)/11]$

$= 27.18$ K ✓

WALE DESIGN

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

MAX ANCHOR FORCE, ROW 1 → 66.10 K
" " ", ROW 2 → 51.41 K
" " ", ROW 3 → 58.76

SECTION MODULUS, $S_{W1} = R_i d^2/14.4S$

ROW 1: $S_{W1} = 66.1 * 8^2/14.4*4 = 73.4$ IN³
ROW 2: $S_{W2} = 51.41 * 8^2/14.4*4 = 57.12$ IN³
ROW 3: $S_{W3} = 58.76 * 8^2/14.4*4 = 65.29$ IN³

ANCHORS

ROW	REQ'D CAPACITY	BONDED LENGTH	UNBONDED LENGTH
1	132.7 K	13.7 FT	16.55 FT
2	103.2 K	9.4 FT	11.03 FT } USE 15 FT
3	118.0 K	11.4 FT	5.5 FT }

$CAPACITY = R_i * (H/S)/\cos\theta$

USE $\theta = 5°$

$CAPACITY = R_i * (8/4)/\cos 5° = 2.0076 R_i$

ROW 1 → CAPACITY $(U_1) = 2.0076 * 66.1 = 132.7$ K

ASSUME MEDIUM TO COARSE SAND

BONDED LENGTH, $L = 10^{(U+74.5)/182.4}$

$L_1 = 10^{(132.7+74.5)/182.4)} = 13.7'$

UNBONDED LENGTH, $L_u = (H - A_1) * \frac{\sin(45° - \phi/2)}{\sin(45° + \phi/2 + \theta)}$

$L_{u_1} = (35-5) * \sin(45 - 30/2)/\sin(45 + 30/2 + 5)$
$= 16.55$ FT

LAGGING SIZE ⟶ USE 3" × 12" FROM FHWA-RD-75-128 (1976).

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

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:

Soil Type	Elev	Unit Wt	Friction Angle or Cohesion
sand	10.00	0.1100	30.00
sand	3.00	0.1150	35.00
sand	-4.00	0.1180	38.00

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

STAGE	ZERO SHEAR (ft)	MAXIMUM MOMENT (k-ft)	SECTION MODULUS (in^3)	EMBEDMENT DEPTH (ft)	REACTION(S) (kips)
1	10.9	32.85	13.69	9.7	---
2	23.6	43.25	18.02	6.6	R1 = 23.56
3	17.5	12.32	5.14	3.8	R1 = 44.37
					R2 = 24.65

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.

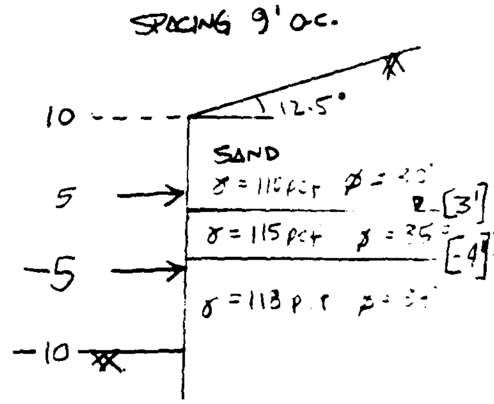
ANCHOR ROW	SECTION MODULUS OF WALE (in^3)	ANCHOR CAPACITY (kips)	ANCHOR LENGTH (ft)	UNBONDED LENGTH (ft)
1	27.7	45	6.0	7.4
2	15.4	25	4.4	2.5

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

SAND EXAMPLE 2

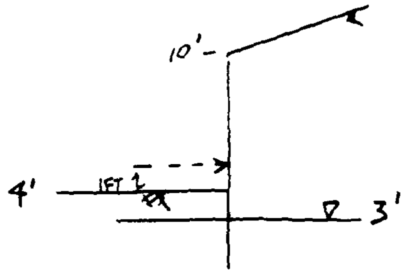


SLOPED BACKFILL —

$$K_a = \frac{\cos^2\phi}{\cos(2\phi/3)\left[1+\sqrt{\frac{\sin(5/3\,\phi)\sin(\phi-\beta)}{\cos(2\phi/3)\cos\beta}}\right]^2}$$

$\beta = 12.5°$

STAGE I:



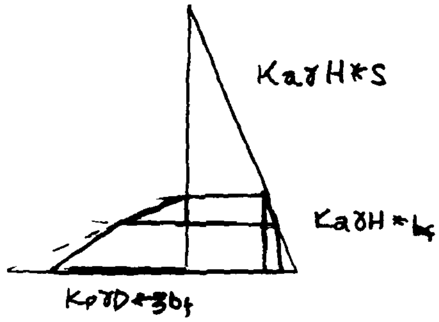
$\gamma_c = 110\,pcf = 0.110\,ksf$
$\phi_c = 30°$

$\gamma_B = 0.110\,kcf$ & $\phi_B = 30°$

$K_a = 0.354$

$K_{p_b} = \tan^2(45+\phi/2) = 3 \qquad K_{a_b} = 1/3$

PT OF ZERO SHEAR:



$P_s = K_a\gamma H^2/2 * S = 0.354(.11)(6)^2/2 * 9$
$= 6.31$ KIPS

ASSUME FS = 1 & bf = 1

$\Sigma V = 0 = P_s + K_{ab}(\gamma H)b_f * Z - (3K_p/FS - K_{ab})\gamma\, b_f * Z^2/2$
$+ (3K_p/FS - K_{ab})\gamma_w\, b_f\,(Z-1)^2/2$

$= 6.31 + 1/3(.11*6)*1*Z - (9 - 1/3)(.11*1)*Z^2/2 +$
$(9-1/3)(0.0624)(Z-1)^2/2$

$= 6.31 + 0.22Z - 0.477*Z^2 + 0.270(Z-1)^2 = 0$

$Z = 4.9\,ft + h = 10.9\,ft.$ ✓

MAX. MOMENT; $M_{max} = \Sigma M_Z$

$\Sigma M_Z = P_s*(h/3 + Z) + K_{ab}(\gamma H)b_f * Z^2/2 - (3K_p/FS - K_{ab})\gamma b_f Z^3/6$
$+ (3K_p/FS - K_{ab})\gamma_w\, b_f\,(Z-1)^3/6$

$$\Sigma M_z = 6.31(6/3 + 4.9) + 1/3(.11*6)*4.9^2/2 - (3*3 - 1/3)(.11)*4.9^3/6$$
$$+ (3*3 - 1/3)\,0.0624\,(4.9-1)^3/6$$

$M_{MAX} = 32.83$ k.ft

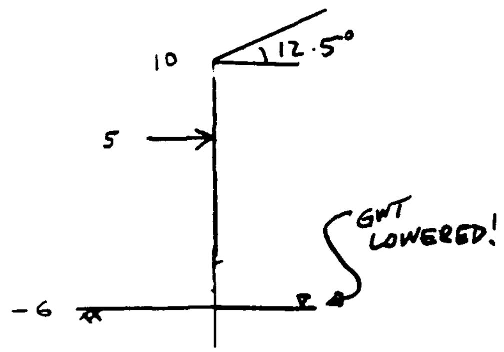
$S = M_{MAX}/2.4 = 13.68$ in^3

EMBEDMENT DEPTH: $\Sigma M_D = \emptyset$.

$$\Sigma M_D = 6.31(2+D) + 1/3(.11*6)*D^2/2 - (9 - 1/3)(.11)D^3/6 + (9-1/3)(0.0624)(D-1)^3/6 = \emptyset$$
$$= 6.31(2+D) + 0.11D^2 - 0.159D^3 + 0.090(D-1)^3 = \emptyset$$

$D = 9.6$ ft

STAGE II:



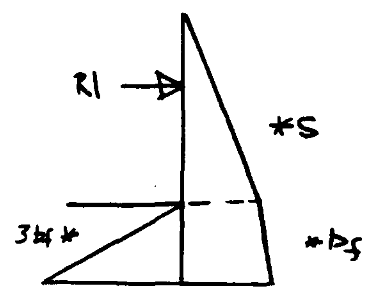
$$\gamma_{AVE} = [7*0.11 + 7*0.115 + 2*0.118]/16$$
$$= 0.1132 \text{ kcf}$$

$\phi_{AVE} = 33.2°$

$\gamma_b = 0.118$ & $\phi_b = 38°$

$K_a = 0.3078$

$K_p = 4.204$ & $K_{ab} = 0.239$



DETERMINE PT WHERE NET FORCES ON EMBEDDED PILE & ASSUME HINGED.

$$P_S = K_a \gamma H^2/2 * S = 0.3078*.1132*16^2/2*9$$
$$= 40.14 \text{ k}$$

$$(3K_p/fs - K_{ab})\, b_f(\gamma - \gamma_w) = pp = (3*4.204 - 0.239)*1*(0.118 - .0624)$$

$pp = 0.688$ k/ft

$$\Sigma F_Y = P_S + K_{ab}\gamma H X - pp * X^2/2$$
$$= 40.14 + 0.239*0.1132*16X - 0.688X^2/2$$
$$= 40.14 + 0.433X - 0.344X^2 \longrightarrow X = 11.5 \text{ FT}$$

REACTION FORCE (ASSUME HINGED AT X, ie ZERO MOMENT).

$$\Sigma M_x = P_s * (h/3 + x) + K_{ab}\gamma H x^2/2 - pp\, x^3/6 - R1(11 + x) = \emptyset$$

$$= 40.14(16/3 + 11.5) + 0.433(11.5)^2/2 - 0.688(11.5)^3/6 - R1(11 + 11.5) = \emptyset$$

$$= 530 - 22.5 R1 = 0 \longrightarrow R1 = 23.55 \text{ KIPS}$$

ZERO SHEAR

$$\Sigma V = 0 = P_s + K_{ab}\gamma H z - pp * z^2/2 - R1 = \emptyset$$

$$= 40.14 + 0.433 z - 0.344 z^2 - 23.55 = \emptyset$$

$$= 16.64 + 0.433 z - 0.344 z^2 \longrightarrow z = 7.6 \text{ ft} + 16 = 23.6'$$

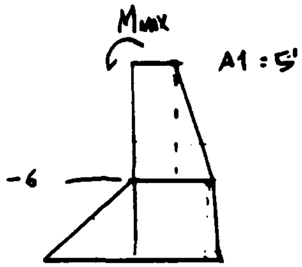
MAX MOMENT

$$\Sigma M_z = P_s * (h/3 + z) + K_{ab}\gamma H z^2/2 - pp\, z^3/6 - R_1(11 + z)$$

$$= 40.14(16/3 + 7.6) + 0.433(7.6)^2/2 - 0.688(7.6)^3/6 - 23.55(11 + 7.6)$$

$M_{MAX} = 43.80$ K-ft $\qquad S = M_{max}/2.4 = 18.25$ IN^3

EMBEDMENT DEPTH



$$\Sigma M_{A1} = M_{max} + pp * D^2/2 * (2D/3 + 11)$$
$$- K_a\gamma A1 * 11^2/2 * S - K_a\gamma 11^2/2 * (2/3 * 11) * S$$
$$- K_{ab}\gamma h D (D/2 + 11) b_f = \emptyset$$

$$= 43.8 + 0.344 D^2 (2D/3 + 11) - 0.3078 * 0.1132 * 5 * 11^2/2 * 9$$
$$- 0.3078(0.1132)\, 11^3 (2/6) * 9 - 0.239(0.1132)(16 D)(D/2 + 11) = \emptyset$$

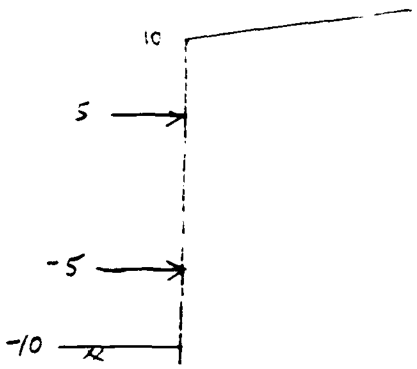
$$= -190.2 + 0.344 D^2 (2D/3 + 11) - 0.433 D (D/2 + 11)$$

$$D = 6.6 \text{ ft}$$

STAGE III:

$$\gamma_{AVE} = \frac{7*0.11 + 7*0.115 + 6*0.118}{20}$$

$= 0.114$ kcf



$\phi_{AVE} = 34.15°$

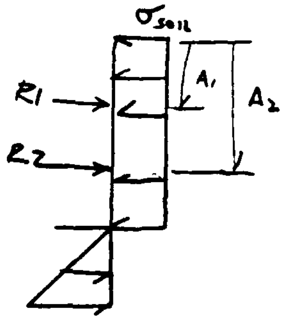
$\gamma_b = .118$ kcf & $\phi_b = 38°$

$K_a = 0.2953$

$K_p = 4.204$

$\sigma_{SOIL} = 0.65 K_a \gamma H S = 0.65*(0.2953)(0.114)(20)*9$

$= 3.94$ KSF



REATION FORCES

$R1 = \sigma_s * A_2^2 / 2(A_2 - A_1) = 3.94*15^2/2(15-5)$

$R1 = 44.33$ K ✓

$R2 = [\sigma_s h^2/2 - R_1(h - A_1)] / (h - A_2)$

$= [3.94*20^2/2 - 44.33*(20-5)] / (20-15)$

$R2 = 24.61$ k ✓

ZERO SHEAR

$\Sigma V = 0 = R1 + R2 - \sigma_s * Z$

$Z = (44.33 + 24.61)/3.94 \longrightarrow Z = 17.5'$ ✓

MAX MOMENT ΣM_z

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

$= 44.33(17.5-5) + 24.61(17.5-15) - 3.94*17.5^2/2$

$M_{MAX} = 12.34$ k-ft ✓

$S = M_{MAX}/2.4 = 5.14$ in^3 ✓

EMBEDMENT DEPTH

$\Sigma M_{A2} = M_s + 3K_p/FS(\gamma-\gamma_w)\,\omega D^2/2\,(2D/3+5) - \sigma_s(5)^2/2 = \phi$

$= 12.34 + (3*4.204*0.0556)D^2/2\,(2D/3+5) - 3.34(5)^2/2$

$= -36.91 + 0.3506D^2(2D/3+5) = \phi$

$D = 3.75$ FT ✓

DMIN → USE $M_s = 43.8$

$\Sigma M_{A2} = -5.45 + 0.3506\,D^2(2D/3+5) = \phi$

$D_{MIN} = 1.6$ FT ✓

CANTILEVER ANALYSIS (NOT INCLUDED IN PROGRAM)

STAGE 1

$M_{MAX} = SK_a\gamma \ell^3/6 = 9*0.354*0.110*6^3/6$

$= 12.62$ K·FT ✓

STAGE 2

$P = K_a\gamma S/40 * (x^5 - 5\ell^4 x + 4\ell^5)/(\ell-x)^3 \qquad x = A_1$

$= 0.3078*0.1132*9/40*(5^5 - 5(16)^4 5 + 4*16^5)/(16-5)^3$

$P = 15.07$ K ✓

$M_{MAX} = SK_a\gamma\ell^3/6 - P(\ell - x)$

$= 9*0.3078*0.1132*16^3/6 - 15.07(16-5)$

$M_{MAX} = 48.30$ K ✓

KIEWIT ANALYSIS

STAGE 1

$M_{K_1} = K_a\gamma H^2/2 * S(H/3+2) = 0.354*.11*6^2/2*9*(6/3+2)$

$= 25.2$ K·FT ✓

STAGE 2

$$M_{k2} = K_a S (H-A_1)^2 * \gamma/2 \, (H+A_1)/9$$

$$= 0.3078 * 9(11)^2 * \frac{0.1132}{2} (16+5)/9$$

$$M_{k2} = 44.27 \text{ k·ft}$$

$$R_{K1} = K_a \gamma S A_1^2/2 + \left[K_a S (H-A_1)^2/2 \, (\gamma A_1) + (H-A_1)^3 K_a \gamma S/6\right]/(H-A_1)$$

$$= 0.3078 * 0.1132 * 9(5)^2/2 +$$

$$\left[0.3078 * 9(11)^2/2 \, (0.1132 * 5) + (11^3)(0.3078)(0.1132)\, 9/6\right]/11$$

$$R_{K1} = 18.87 \text{ K}$$

ANCHORS

$R_{1\,MAX} = 44.33$ K
$R_{2\,MAX} = 24.61$ K

SPACING OF ANCHORS → d = 9 FT
INCLINATION ANGLE → $\theta = 10°$

ANCHOR CAPACITY FOR TOP ROW, $U_1 = 44.33 * (9/9)/\cos 10°$

$U_1 = 45.0$ K — SPACING OF ANCHOR/PILE SPACING

ANCHOR CAPACITY FOR BTM ROW, $U_2 = 24.61 * (9/9)/\cos 10°$

$U_2 = 25.0$ K

~~BONDED LENGTH:~~
~~ASSUME FINE~~ TO MEDIUM SAND: $L = 10^{(U_i + 68.9)/147}$

$L_{A1} = 10^{(45+68.9)/147}$ $L_{A2} = 10^{(25+68.9)/147}$

$L_{A1} = 5.95$ FT $L_{A2} = 4.35$ FT

UNBONDED LENGTH: $L_u = (H - A_i) * \frac{\sin(45 - \phi/2)}{\sin(45 + \phi/2 + \theta)}$

$L_{u1} = (20-5) * \sin(45 - 34.15/2)/\sin(45 + 34.15/2 + 10)$

$L_{u1} = 7.4$ FT

$L_{u2} = (20-15)\,\sin(45-34.15/2)/\sin(45+34.15/2+10)$

$L_{u2} = 2.46$ FT ✓

WALE SECTION MODULUS:

$S_W = R_A d^2 / 14.4 S$

ROW 1:

$S_{W1} = 44.33 * 9^2 / 14.4 * 9$

$S_{W1} = 27.7$ IN^3

ROW 2

$S_{W2} = 24.61 \times 9^2 / 14.4 * 9$

$S_{W2} = 15.4$ IN^3 ✓

∴ E.O.A.

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

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:

Anchor	Elevation (feet)
1	90.0υ
2	80.00
3	70.00

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:

Soil Type	Elev	Unit Wt	Friction Angle or Cohesion
clay	100.00	0.1100	0.50
clay	85.00	0.1200	1.75

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 SHEAR (ft)	MAXIMUM MOMENT (k-ft)	SECTION MODULUS (in^3)	EMBEDMENT DEPTH (ft)	REACTION(S) (kips)
1	13.6	119.25	49.69	7.5	---
2	24.3	91.14	37.98	2.1	R1 = 44.13
3	25.1	150.38	62.66	2.2	R1 = 194.47
					R2 = 80.75
4	34.7	123.01	51.25	2.1	R1 = 211.11
					R2 = 103.15
					R3 = 128.81

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.

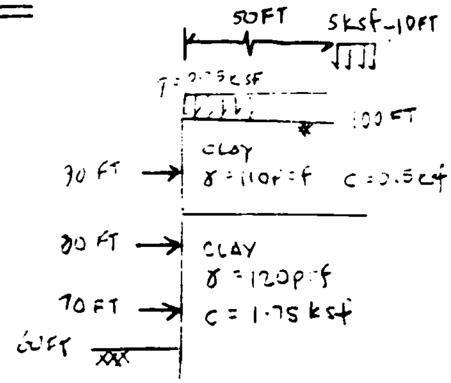
ANCHOR ROW	SECTION MODULUS OF WALE (in^3)	ANCHOR CAPACITY (kips)	ANCHOR LENGTH (ft)	UNBONDED LENGTH (ft)
1	73.3	213	27.1	26.7
2	35.8	104	13.3	17.8
3	44.7	130	16.5	8.9

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

CLAY EXAMPLE W/O WTR TABLE



- SPACING 5 FT O.C.
- PASSIVE FACTOR OF SAFETY = 1.
- ESTIMATED WIDTH OF SOLDIER PILE, $b_f = 1.$
- OVEREXCAVATED 1 FT BELOW ANCHOR.

STAGE I

CUT: $\gamma = .110$ kcf & $c = 0.5$ ksf

BASE: $C_{AVE} = \dfrac{4 * 0.5 + 16 * 1.75}{20} = 1.5$ ksf

EQUIVALANT q FOR STRIP LOAD:

$\theta_2 = \tan^{-1}(a + b/h)$

$= \tan^{-1}((10+50)/11) = 1.389$

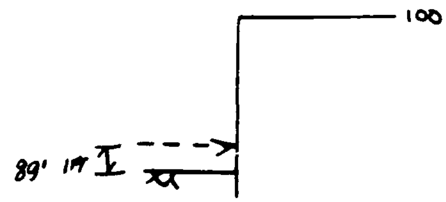
$\theta_1 = \tan^{-1}(b/h)$

$= \tan^{-1}(50/11) = 1.354$

$q_e = P/h = 2q\,h/\pi * (\theta_2 - \theta_1)/h$

$= 2 * 5/\pi * (1.389 - 1.354)$

$q_e = 0.112$ ksf

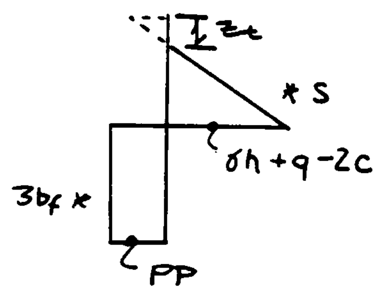


TENSION ZONE:

$Z_t = (2c - q)/\gamma$

$Z_t = (2*0.5 - (0.75 + 0.112))/0.11$

$= 1.25$ FT



STRESSES:

$\sigma_s = [\gamma h + q - 2c]^{*S} = [0.11*11 + (.75 + .112) - 2*0.5] * 5$

$\sigma_s = 5.375$ ksf

$PP = (2c_b * 3 - (\gamma H + q - 2c_b) * b_f$

$= (8c_b - \gamma H - q) * b_f$

$= [8 * 1.5 - 0.11 * 11 - (0.75 + 0.11)] * 1$

$PP = 9.93$ ksf

PT OF ZERO SHEAR:

$\Sigma V = 0 = \sigma_s * (h - Z_t)/2 - pp * Z$

$Z = 5.375 * (11 - 1.25)/2 / 9.93$

$Z = 2.6' + 11'(h) = 13.6$ FT ✓

MAX MOMENT: $\Sigma M_Z = M_{MAX}$

$\Sigma M_Z = \sigma_s * (h - Z_t)/2 * ((h - Z_t)/3 + Z) - pp\, Z^2/2$

$= 5.375 * (11 - 1.25)/2 * ((11 - 1.25)/3 + 2.6) - 9.93 * 2.6^2/2$

$= 119.72$ k·ft ✓

$S = M/2.4 = 119.72/2.4 = 49.89\ in^3$ ✓

DEPTH OF EMBEDMENT

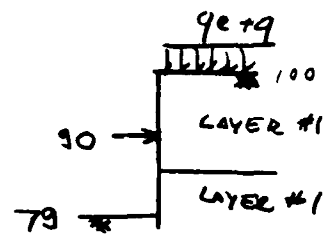
$\Sigma M_D = 0 = \sigma_s (h - Z_t)/2 * [(h - Z_t)/3 + D) - pp * D^2/2$

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

$= 26.20 * (3.25 + D) - 4.965 D^2 = 0$

$\therefore D = 7.55$ FT ✓

STAGE II:



CUT: $\gamma_{AVE} = (15 * .11 + 6 * .12)/21$

$= 0.1129$ kcf

$C_{AVE} = (15 * .5 + 6 * 1.75)/21$

$= 0.857$ ksf

BASE: $C = 1.75$ ksf

qe STRIP:

$\theta_2 = TAN^{-1}(60/21) = 1.234$

$\theta_1 = TAN^{-1}(50/21) = 1.173$

$q_e = 10/\pi * (1.234 - 1.173) = 0.194$ ksf

TENSION ZONE:

$Z_t = (2 * 0.857 - (0.75 + 0.194)) / 0.1129$

$= 6.82\ FT > Z_t$ STAGE 1 $= 1.25\ FT$

USE $Z_t = 1.25\ FT$

FIND PT OF NET ZERO FORCES IN EMBEDDED PILE

$\sigma_s = (0.1129 * 21 + 0.75 + 0.194 - 2 * 0.857) * 5$

$= 8.005\ ksf$

$PP = (8 * 1.75 - 0.1152 * 21 - (0.75 + .194)) * 1$

$= 10.64\ ksf$

$\Sigma F_y : 0 = \sigma_s (h - Z_t)/2 - PP * X$

$X = 8.005 * (21 - 1.25)/2 / 10.64$

$X = 7.43\ FT$

REACTION FORCE (ASSUME HINGED @ X - ZERO MOMENT)

$\Sigma M_x = \sigma_s * (h - Z_t)/2 * [(h - Z_t)/3 + X] - PP * X^2/2 - R_1 (h - A1 + X) = 0$

$= 8.005 * (21 - 1.25)/2 [(21 - 1.25)/3 + 7.43] - 10.64 * 7.43^2/2 - R_1 (21 - 10 + 7.43)$

$R_1 = 44.17\ KIPS$ ✓

ZERO SHEAR

$\Sigma V = 0 = \sigma_s (h - Z_t)/2 - PP * Z - R_1$

$= 8.005 (21 - 1.25)/2 - 10.64 Z - 44.17$

$Z = 3.28\ FT \quad + 21 = 24.28\ FT$ ✓

MAX MOMENT

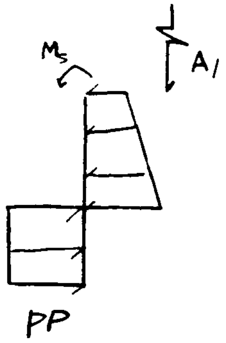
$\Sigma M_z = \sigma_s * (h - z_t)/2 \left[(h - z_t)/3 + z \right] \cdot pp \cdot z^2/2 - R_1 (h - A_1 + x)$

$= 8.005(21 - 1.25)/2 \left[(21 - 1.25)/3 + 3.23 \right] - 10.64 \cdot 3.23^2/2 - 44.17$ (21 - [illegible] + 3.23)

$M_{MAX} = 91.71$ K-FT ✓

$S = 38.21 \ IN^3$ ✓

EMBEDMENT DEPTH

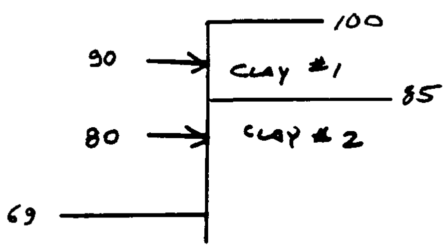


$\Sigma M_{A_1} = M_s + pp * D * (D/2 + h - A_1) -$
$s * \left[\gamma (h - A_1) + q - 2c \right] * (h - A_1)^2/2 -$
$2 s \gamma (h - A_1)^3/6 = \phi$

$= 91.71 + 10.64 D (D/2 + 11) - 5 * \left[0.1129 (10) + (0.75 + 1.94) - 2 * 0.857 \right]$
$* (11)^2/2 - 2 * 5 * 0.1129 (11)^3/6$

$= 25.13 - D(D/2 + 11) \rightarrow D = 2.09$ FT ✓

STAGE III



$\gamma_{AVE} = \left[15 * 0.11 + 16 * 0.12 \right] / 31$
$= 0.1152$ KCF

$C_{AVE} = (15 * 0.5 + 16 * 1.75)/31$
$= 1.145$ KSF

$C_b = 1.75$ KSF

qe STRIP

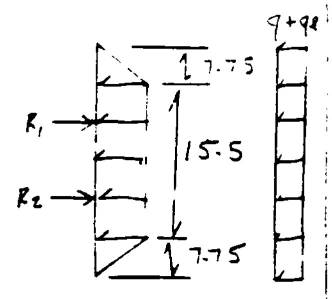
$\theta_2 = \tan^{-1}(60/31) = 1.094$
$\theta_1 = \tan^{-1}(50/31) = 1.016$

$q_e = 10/\pi * (1.094 - 1.016) = \phi.247$ KSF

STABILITY NUMBER, N_S

$N_s = \gamma H / C$

$= 0.1152 * 31 / 1.145 = 3.12$



USE PRESSURE DISTRIBUTION

$\sigma_h = 0.4 \gamma H$

$\sigma_h = 0.4 * 0.1152 * 31 * 5$

$= 7.14$ Ksf

$q + q_e = 0.997$ Ksf

$pp = (8c - (q + q_e)) * b_f$ — NEGLECT SOIL PRESSURE BELOW CUT

$= (8 * 1.75 - 0.997) * 1 = 13.00$ Ksf

REACTION FORCES

$\Sigma M_{R_2} = 0 = 7.14 * 7.75/2 * (7.75/3 + 12.25) +$

$7.14 * 12.25^2/2 + 0.997 * 5 * 20^2/2 - R_1 (10)$

$R_1 = 194.31$ Kips ✓

$\Sigma M_{BASE} = 7.14 * 7.75/2 * (7.75/3 + 23.25) + 7.14 * 15.5 (15.5/2 + 7.75)$

$7.14 * 7.75^2/3 + 0.997 * 5 * 31^2/2 - 194.31 * (31 - 10) - R_2 (11) = 0$

$R_2 = 80.71$ K ✓

ZERO SHEAR

$\Sigma V = 0 = 194.31 + 80.71 - 7.14 * 7.75/2 - 7.14 * 15.5 - 5 * 0.997 * z$

$- 5 * 0.1152 (31 - 0.8z)(z - 0.75(31))$

$= 136.7 - 4.985 z - 0.576 * (31 - .8z)(z - 23.25)$

$z = 25.1$ FT ✓

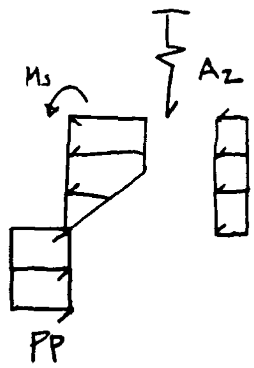
MAX MOMENT

$\Sigma M_Z = 194.31*(15.1) + 80.71*5.1 - 7.14*7.75/2*(25.1-2(7.75)/3)$
$- 7.14*15.5*(25.1-15.5) - 5*0.997*25.1^2/2$
$- 0.9*5*0.1152(25.1-0.75*31)^2*(31-2/3*25.1)$

$M_{MAX} = 150.21$ K·FT

$S = 62.59$ IN^3

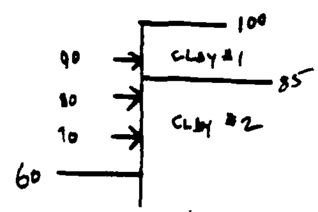
EMBEDMENT DEPTH



$\Sigma M_{RZ} = 150.2 + 13D(D/2+11) -$
$7.14*(11-7.75)^2/2 - 7.75*7.14/2*$
$(7.75/3 + (11-7.75)) - 5*0.997*11^2/2$
$= 26.96 - D(D/2+11)$

$D = 2.23$ FT

STAGE IV



$\gamma_{AVE} = (15*0.11 + 25*0.12)/40$
$= 0.11625$ Kcf

$C_{AVE} = (15*0.5 + 25*1.75)/40$
$= 1.28$ ksf

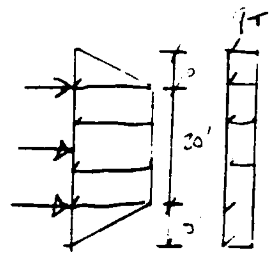
$C_b = 1.75$ ksf

STABILITY NUMBER

$N_s = 0.11625*40/1.75 = 2.7$

$\sigma_h = 0.4\gamma H * S = 0.4 * .11625 * 40 * 5$

$= 9.3 \text{ ksf}$



$PP = 13 \text{ ksf}$

q_e STRIP → $\theta_2 = \tan^{-1}(60/40) = 0.983$
$\theta_1 = \tan^{-1}(50/40) = 0.896$

$q_e = 10/\pi * (0.983 - 0.896)$

$= 0.276 \text{ ksf}$

$q_T = q + q_e = 1.026 \text{ ksf}$

REACTION FORCES

$\Sigma M_{R1} = 9.3*10/2*(10/3+10) + 10^2*9.3/2 + 1.026*5*20^2/2 - R_1(10) = 0$

$R_1 = 211.1$ kips

$\Sigma M_{R2} = 9.3*10/2\,(10/3+20) + 9.3*20^2/2 + 1.026*5*30^2/2$
$- 211.1*10 - 10R_2 = \emptyset$

$R_2 = 103.15$ k

$\Sigma M_{BASE} = 9.3*10/2\,(10/3+30) + 9.3*20(20/2+10) +$
$9.3*10/2*(2/3*10) + 1.026*5*40^2/2 -$
$211.1*30 - 103.15*20 - R_3*10 = \emptyset$

$R_3 = 128.8$ k

ZERO SHEAR

$\Sigma V = 0 = 211.1 + 103.15 + 128.8 - 9.3*10/2 - 9.3*20 - 1.026*5*Z$
$-5*0.11625(40-0.8Z)(Z-30)$

$= 210.55 - 5.13Z - 0.58125(40-0.8Z)(Z-30)$

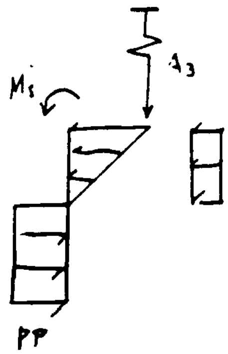
$Z = 34.6$ FT

MAX MOMENT

$$\Sigma M_3 = 211.1 * 24.6 + 103.15 * 14.6 + 128.3 * 4.6 - 9.3 * 10/2 * (34.6 - 20/3) - 9.3 * 20 (34.6 - 20) - 1.026 * 5 * 34.6^2/2 - 0.11625 * 5 * 0.9 (34.6 - 30)^2 (40 - 34.6(2/3))$$

$M_{max} = 123.01$ K·FT ✓

$S = 51.25$ IN^3



DEPTH OF EMBEDMENT

$$\Sigma M_{R3} = 0 = 123.01 + 13 * D(D/2 + 10) - 9.3 * 10/2 * 10/3 - 1.026 * 5 * 10^2/2$$

$$= 22.19 - D(D/2 + 10)$$

$D = 2.02$ FT ✓

MIN. D BASED ON MMAX OF ALL STAGES

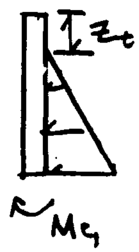
$M_{MAX} = 150.21$ (STAGE III

$$\Sigma M_{R3} = 150.21 + 13 D(D/2 + 10) - 411.5$$

$$= -20.10 + D(D/2 + 10) \longrightarrow D_{MIN} = 1.84 \text{ FT}$$ ✓

CANTILEVER (NOT INCLUDED IN PROGRAM)

STAGE 1:

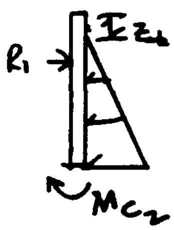


$$M_{c_1} = 5 * (\gamma h + q_T - 2c)(h - Z_t)^2/6$$

$$= 5 * (.11 * 11 + 0.862 - 2 * 0.5)(11 - 1.25)^2/6$$

$M_{c_1} = 84.92$ K·FT ✓

STAGE 2:



$$R_1 = \{5 * (21 * .1129 + 0.944 - 2 * 0.857) * (21 - 1.25)/2 / (21 - 1.25)^2 * [(10 - 1.25)^5 - 5 * (21 - 1.25)^4 * (10 - 1.25) + 4(21 - 1.25)^5]\} / [20 * (21 - 10)^3] \longrightarrow R_1 = 41.22 K$$ ✓

$M_{c_2} = 5 * (21 * .1129 + 0.944 - 2 * 0.857)(21 - 1.25)/2 * (21 - 1.25)/3$

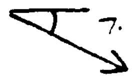
$- 41.22(21 - 10)$

$= 66.96 \text{ k·ft}$ ✓

ANCHORS

ROW 1 → R_{max} = 211.11
" 2 → R_{max} = 103.15
" 3 → R_{max} = 128.8

ANCHOR SPACING = 5 FT
AT 7.5° ANGLE



REQUIRED CAPACITY: $U_i = R_i / \cos\theta * d/s$

$U_1 = 211.11 / \cos 7.5 * 5/5 = 212.9 \text{ k}$ ✓
$U_2 = 103.15 / \cos 7.5 = 104.0 \text{ k}$ ✓
$U_3 = 128.8 / \cos 7.5 = 129.9 \text{ k}$ ✓

BONDED LENGTH ASSUME STIFF TO V. STIFF CLAY.

$L = U / 7.85$

$L_1 = 212.9 / 7.85 = 27.1 \text{ FT}$ ✓
$L_2 = 104 / 7.85 = 13.2 \text{ FT}$ ✓
$L_3 = 129.9 / 7.85 = 16.5 \text{ FT}$ ✓

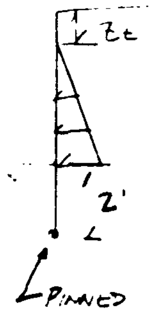
UNBONDED LENGTH $\phi = 0°$ $L_u = 0.891(h - A_i)$

$L_{u1} = 0.891(40 - 10) = 26.7 \text{ FT}$ ✓
$L_{u2} = 0.891(40 - 20) = 17.8 \text{ FT}$ ✓
$L_{u3} = 0.891(40 - 30) = 8.9 \text{ FT}$ ✓

WALES $S_{wi} = R_i d^2 / 14.4 S = 0.347 R_i$

$S_{w1} = 0.347 * 211.11 = 73.3 \text{ in}^3$ ✓
$S_{w2} = 0.347 * 103.15 = 35.8 \text{ in}^3$ ✓
$S_{w3} = 0.347 * 128.8 = 44.7 \text{ in}^3$

KIEWIT CRITERIA



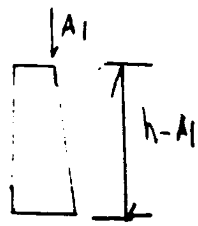
STAGE I:

$M_K = \sigma_s * (h - Z_t)/2 * ((h - Z_t)/3 + 2)$

$= 5.375 * (11 - 1.25)/2 * ((11 - 1.25)/3 + 2)$

$= 137.6 \ k \cdot ft$ ✓

STAGE II:



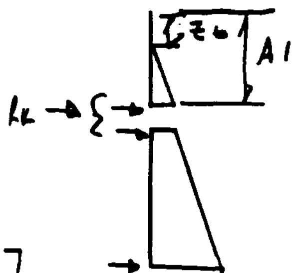
$M_{K2} = \omega_{AVE} \, l^2/9$

$\omega_{AVE} = [(q_e - 2c + \gamma A_1) + \gamma(h - A1)/2] * S$

$= [0.75 + .194 - 2 * .857 + 0.1129(10) + 0.1129\frac{(21-10)}{2}] * 5$

$= 4.9 \ ksf$

$M_{K2} = 4.9 * 11^2/9 = 65.9 \ k \cdot ft$ ✓



$R_K = 5 * [(q_e - 2c + \gamma A1)(A1 - Z_t)/2 + \{(q_e - 2c + \gamma A1)(h - A1)^2/2 + \gamma(h - A1)^3/6\}/(h - A1)]$

$= 5 * [(.75 + .194 - 2 * .857 + .1129 * 10)(10 - 1.25)/2 + \{(.75 + .194 - 2 * .875 + .1129 * 10)(11)^2/2 + .1129 * 11^3/6\}/11]$

$= 29.1 \ k \cdot ft$ ✓

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

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 follow:

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 SHEAR (ft)	MAXIMUM MOMENT (k-ft)	SECTION MODULUS (in^3)	EMBEDMENT DEPTH (ft)	REACTION(S) (kips)
1	0.0	0.00	0.00	0.0	---
2	23.5	5.39	2.24	5.1	R1 = 4.26
3	20.0	41.81	17.42	4.4	R1 = 65.60
					R2 = 65.84

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.

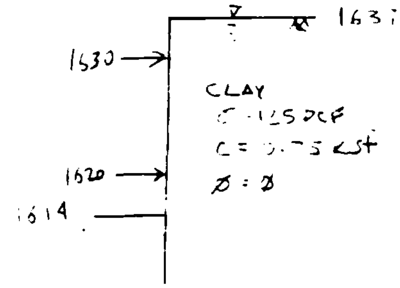
NOTE: A effective stress analysis approach was used.

E N D O F A N A L Y S I S

CLAY EXAMPLE PROBLEM #2

(WTR TABLE AT GRD LEVEL)

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

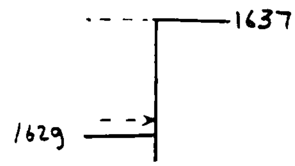


SPACING — 6 FT O.C.

STAGE I

$\gamma_b = 125 - 62.4 = 62.6\,pcf$

$\gamma_w = 62.4$



TENSION ZONE

$\gamma_b * z_t + \gamma_w z_t - 2c = \phi$

$z_t = 2c/(\gamma_b + \gamma_w)$

$= 2 * 0.75/(0.0626 + 0.0624)$

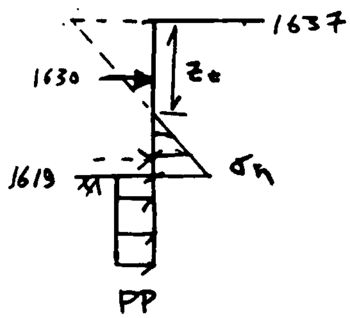
$z_t = 12\ FT$

$h = 8$

$z_t > h \longrightarrow$ NEGLECT STRESSES W/I TENSION ZONE.

$\therefore\ M_{max} = \phi$

STAGE II



TENSION ZONE:

$z_t = 12$

STRESSES - FORCES

$P_a = (\gamma h - 2c)(h - z_c)/2 * S$

$= (0.125*18 - 2*0.75)(18-12)/2 * 6$

$= 13.5$ KIPS

$PP = (6c/_{FS} - (\gamma h - 2c)) b_f$

$= [6*0.75/1.5 - (0.125*18 - 2*0.75] * 0.75$

$= 1.6875$ KSF

NET ZERO FORCES ON EMBEDDED PILE

$\Sigma F_y = 0 = 13.5 - 1.6875 x$

$x = 8$ FT

REACTION FORCE

$\Sigma M_x = 0 = P_a((h - z_c)/3 + x) - PP * x^2/2 - R_1(h - A1 + x)$

$= 13.5*((18-12)/3+8) - 1.6875*8^2/2 - R_1(18-7+8)$

$R_1 = 4.26$ kips ✓

ZERO SHEAR

$\Sigma V = 0 = 13.5 - 1.6875 z - 4.26$

$z = 5.5$ FT $+ 18 = 23.5$ FT ✓

MAX. MOMENT

$\Sigma M_z = 13.5*(6/3 + 5.5) - 1.6875*5.5^2/2 - 4.26*(11+5.5)$

$M_{max} = 5.44$ K.FT ✓

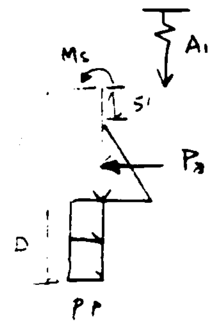
$S = 2.27$ IN^3 ✓

DEPTH OF EMBEDMENT

$\Sigma M_{R_1} = 0 = 5.44 + 1.6875 D(D/2 + 11)$
$- 13.5(11 - 6/3)$

$= D(D/2 + 11) - 68.73$

$D = 5.1$ FT



STAGE III

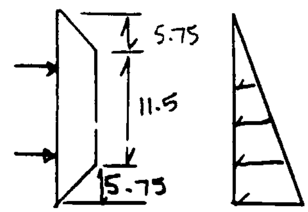
$N_s = \gamma h / c = 0.0626 * 23/0.75$

$= 1.9$

$\sigma_h = 0.4 \gamma H * S$

$= 0.4 * 0.0626 * 23 * 6$

$= 3.46$



REACTION FORCES

$\Sigma M_{R2} = 3.46 * 5.75/2 * (5.75/3 + 11.25) + 0.0624 * 17^2/2 * 6(17/3)$
$+ 3.46 * 11.25^2/2 - 10R_1 = 0$

$R_1 = 65.65$ KIPS ✓

$\Sigma M_{BASE} = 3.46 * 5.75/2 * (5.75/3 + 17.25) + 3.46 * 11.5 * (11.5)$
$+ 0.0624 * 23^3/6 * 6 + 3.46 * 5.75/2 * 2/3(5.75)$
$- 16 * 65.65 - 6R_2 = 0$

$R_2 = 65.87$ KIPS ✓

ZERO SHEAR

$\Sigma V = 0 = 65.65 + 65.87 - 3.46 * 5.75/2 - 3.46 * 11.5$
$- 6 * 0.0624 (23 - 0.8z)(z - 17.25) - 0.0624 * 6 z^2/2$

$= 81.78 - 0.3744(23 - 0.8z)(z - 17.25) - 0.1872 z^2$

$z = 20$ FT ✓

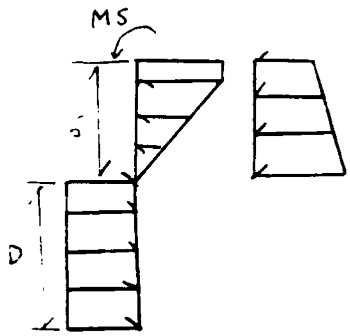
MAX MOMENT

$\Sigma M_Z = 65.65(13) + 65.87(3) - 3.46 * 5.75/2 * (20 - 2/3 * 5.75)$
$- 3.46 * 11.5 * (20 - 11.5) - 0.0624 * 6 (20)^3/6 - 6 * .4(0.0624)(20 - 17.25)^2 *$
$(23 - 2/3(20))$

$M_{max} = 41.88$ k ft ✓

$S = 17.45$ in^3

EMBEDMENT DEPTH

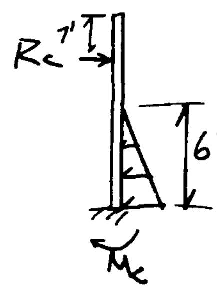


$\Sigma M_{R2} = 0 = 41.88 + (6 * 0.75/1.5 + 2 * 0.75) *$
$0.75 D(D/2 + 6) - 0.25^2/2 * 3.46$
$- 3.46 * 5.75/2 (5.75/3 + 0.25)$
$- 17 * 0.0624 * 6 (6)^2/2 - 0.0624 * 6 * 6^2/2 (2/3 * 6)$

$= 35.94 - D(D/2 + 6) \longrightarrow D = 4.4$ FT ✓

CANTILEVER ANALYSIS (NOT INCLUDED W/I PROGRAM)

STAGE II:



$R_c = 6 * (0.125 * 18 - 2(0.75)) * 6/2 * 6^2 *$
$(6/5 - (12 - 7)/4) / (18 - 7)^3$
$= 0$

$M_c = 13.5 * 6/3 - 0 = 27$ k.FT ✓

KIEWIT CRITERIA:

STAGE II:

$M_t = \omega l^2/9 = P_a/(h - Z_t) * (h - Z_t)^2/9$
$= 13.5 * (18 - 12)/9 = 16.5$ k.ft ✓

$R_t = P_a(h - Z_t)/3/(h - A_1) = 13.5(18 - 12)/3/(18 - 7)$
$= 2.45$ k.ft ✓

APPENDIX E

REFERENCES

American Institute of Steel Construction, Manual of Steel Construction, Eighth Edition, Illinois, 1980.

Boghrat, Alireza, "Use of STABL Program in Tie-Back Wall Design", Journal of Geotechnical Engineering, Volume 115, No. 4, pp. 546-552, New York, April 1989.

Bowles, Joseph E., Foundation Analysis and Design, Fourth Edition, McGraw-Hill Book Company, New York, 1988.

Carpenter, J. R., and S. Kopperman, U.S. Department of Transportation, Federal Highway Administration, PCSTABL4 User Manual, Report Number FHWA-TS-85-229, U.S Government Printing Office, Washington, D.C., 1985.

Cernica, John N., Geotechnical Engineering, Holt, Ricnehart and Wiston, New York, 1982.

Chapman K. R., E. J. Cording, H. Schnabel, Jr., "Performance of Braced Excavations in Granular and Cohesive Soils", Proceedings of the Specialty Conference on Performance of Earth and Earth-Supported Structures, American Society of Civil Engineers, Volume III, pp. 271-293, New York, 1972.

Clough, G. Wayne, "Performance of Tie-Back Support Systems", Proceedings of the Specialty Conference on Performance of Earth and Earth-Supported Structures, American Society of Civil Engineers, Volume III, pp. 259-264, New York, 1972.

Das, Braja M., Principles of Foundation Engineering, Second Edition, PWS-Kent Publishing Company, Massachusetts, 1990.

Goldberg, D. T., W. E. Jaworski, and M. D. Gordon, U.S. Department of Transportation, Federal Highway Administration, Lateral Support Systems and Underpinning, Volume I Design and Construction, Report No. FHWA/RD-75/128, U.S. Government Printing Office, Washington, D.C., 1976.

Jarquio, Ramon, "Total Lateral Surcharge Pressure Due to Strip Load", Journal of the Geotechnical Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 107, No. GT10, pp. 1424-1428, New York, October 1981.

Keorner, Robert M., Construction and Geotechnical Methods in Foundation Engineering, McGraw-Hill Book Company, New York, 1984.

Lambe, T. William, and Edmund K. Turner, "Braced Excavations", Lateral Stresses in the Ground and Design of Earth-Retaining Structures, State-of-the-Art Papers presented at 1970 Specialty Conference, Soil Mechanics and Foundations Division, American Society of Civil Engineers, New York, 1970.

Lambe, T. William, and Robert V. Whitman, Soil Mechanics, John Wiley & Sons, New York, 1969.

Liao, Sam S.C., and Thom L. Neff, "Estimating Lateral Earth Pressures for Design of Excavation Support", Design and Performance of Earth Retaining Structures, Proceedings of a Conference, Geotechnical Engineering Division of American Society of Civil Engineers, New York, June 18-21, 1990

Merritt, Frederick S., Standard Handbook for Engineers, McGraw-Hill Book Company, New York, 1976.

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

Ostermayer, H., "Construction. Carrying Behavior and Creep Characteristics of Ground Anchors", Proceeding of Diaphragm Wall and Anchorages Conference, Institute of Civil Engineers, pp. 141-151, London, England, 1975.

Peck, R. B., "Deep Excavations and Tunneling in Soft Ground", Proceedings, Seventh I.C.S.M.F.E, State of the Art Volume, pp. 225-290, Mexico, 1969.

Terzaghi, K. and P. B. Peck, Soil Mechanics in Engineering Practice, Second Edition, Wiley, New York, 1967.

Turbo C++ User's Guide, Second Edition, Borland International Inc., California, 1991

U. S. Department of the Navy, Naval Facilities Engineering Command, Foundations and Earth Structures, Design Manual 7.2 (NAVFAC DM-7.2), Washington, D.C., 1982.

Ulrich, Edward J., Jr., "Tieback Supported Cuts in Overconsolidated Soils", Journal of Geotechnical Engineering, Volume 115, No. 4, pp. 521-545, New York, April 1989.

U. S. Department of Transportation, Federal Highway Administration, Tiebacks, Report No. FHWA/RD-82/047, U. S. Government Printing Office, Washington, D.C., 1982.