BERMS FOR STABLIZING EARTH RETAINING STRUCTURES

by

YOUSSEF GOMAA YOUSSEF MORSI

B.Sc., Civil Engineering

A Thesis Submitted to The Faculty of Engineering,

Cairo University, Fayoum branch

in Partial Fulfillment

of the Requirements for the Degree of

MASTER OF SCIENCE

in

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FACULTY OF ENGINEERING

CAIRO UNIVERSITY, FAYOUM BRANCH

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2003

DEDICATION

TO MY PARENTS

TO MY BROTHERS

ACKNOWLEDGEMENT

I wish to express my sincere thanks to associate professor: **Emad El-Din Shaarawi** and assistant professor: **Mahmoud Sherif Abdel Baki** who supervised this thesis. They gave me support and guidance throughout this research.

Also, I would like to thank all professors and engineers in the faculty of engineering, Cairo University, Fayoum branch who contributed in their own way to the improvement the content of this thesis, in particular, the soil mechanics and foundation engineering staff in the faculty. I am very grateful to all employees in the faculty especially in the soil mechanics laboratory.

I am indebted to my parents for their effort and constant encouragement for me. Finally, I took a tremendous pleasure in writing this thesis. I hope that all readers and researchers will enjoy and benefit from it. I wish that my research contributes to the progress and development of the research in civil engineering. To all those who have contributed to this humble work or helped in its development and were overlooked and not mentioned, my sincerest apologies are presented.

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NOTATIONAL SYSTEM

Symbol	Term	Unit
δ	Angle of Friction of Soil with The Wall	Degree
φ	Angle of Internal Friction of Soil	Degree
ν	Poisson's Ratio of The Wall Material	-
ε	Vertical Strain of Soil	-
Ψ	Angle of Dilatancy	Degree
β	Back Angle of the Wall with Horizontal	Degree
σ_1	Major Principal Stress	kN/m^2
σ_2	Intermediate Principal Stress	kN/m^2
σ_3	Minor Principal Stress	kN/m^2
γ_d	Dry Unit Weight of Soil	kN/m^3
ν_{ur}	Unloading Reloading Poisson's Ratio of Soil	-
1 : m	The Slope of Berm (VL to HL)	-
Bt	Top Width of Berm	m
C	Cohesion of Soil	kN/m^2
D	Deflection of the Top Point of the Wall	mm
d	Driven Depth of Cantilever Sheet Pile Wall	m
D_{10}	Effective Size of Tested Sand	mm
D_b	Maximum Deflection of the Wall with Berm	mm
Dr	Relative Density of Sand	-
E_{50}	Secant Modulus of Deformation	kN/m^2
EA	Axial Stiffness of Sheet Pile Wall	-
EI	Flexural Rigidity of Sheet Pile Wall	-

Symbol	Term	Unit
Eo	Tangent Modulus of Deformation	kN/m^2
E^{ref}	Reference Stiffness Modulus Corresponding to Reference stress	kN/m^2
E^{ref}_{ur}	Reference Young's Modulus for Unloading Reloading	kN/m^2
E_{ur}	Unloading Reloading Stiffness of Soil	kN/m^2
F_D	Moment Factor for Bermed Cantilever Wall	-
F_m	Deflection Factor for Bermed Cantilever Wall	-
Fs	Factor of Safety for Passive Earth Pressure	-
H	Total Height of Wall	m
Hb	Height of Berm	m
h_{ed}	Equivalent Deflection Height	m
h_{em}	Equivalent Moment Height	m
Hi	Equivalent Increase in Driven Depth	m
H_w	Free Height of Cantilever wall	m
i	Angle of Slope of Ground Surface to Horizontal	Degree
I_m	Inertia of Sheet Pile Model	m^3/m'
Ka	Active Earth Pressure Coefficient	-
K_o	Coefficient of at Rest Earth Pressure	-
Kp	Passive Earth Pressure Coefficient	-
Kpm	Mobilized Passive Earth Pressure Coefficient	-
m	Power in Stiffness Law	-
M_b	Maximum Bending Moment on Cantilever Wall with Berm	kN.m/m'
M_{max}	Maximum Bending Moment on Cantilever wall	kN.m/m'

Symbol	Term	Unit
N	SPT Number	-
n_{max}	Maximum Porosity of Tested Sand	-
n_{min}	Minimum Porosity of Tested Sand	-
P1, P2, Pa	Earth Pressure Forces	kN/m’
P^{ref}	Reference Pressure	kN/m^2
q	Deviatoric Stress	kN/m^2
q_a	The Asymptotic Value of Shear Strength	-
q_f	Ultimate Deviator stress	kN/m^2
R	Force Acting below Point of Rotation of Cantilever Wall	kN
R_f	Failure Ratio	-
Ri	Shear Strength Reduction Factor	-
t_m	Thickness of Sheet Pile Model	mm
W	Unit Weight per Unit Area of the Wall	kN/m’
Wc	Water Content	-

ABSTRACT

Earth retaining structures are used widely in ground engineering. The cantilever sheet pile is considered one of the most common types, the stabilizing berm may be used with these walls to increase the stability and decrease the deflection. Also, the stabilizing berm has a great effect on the settlement reduction of the backfill. The analysis of the stability of the cantilever sheet pile wall may be performed using limit equilibrium or analytical methods.

The limit equilibrium analysis for walls with a stabilizing berm is not easy. It requires graphical solutions and does not yeild any data about the deflection of the wall. Furthermore, graghical solutions although rigours are based on assumed slip surfaces, that in cases may not be correct. There are two approximate methods to analyse this problem without using graphical solutions. The results of these approximate have not been fully verified by comparing with accurate solutions or measurments.

In this research work, the analysis of the cantilever sheet pile wall with stabilizing berm is performed for cohesionless soils with different properties. The cohesionless soil is classified into five groups with different friction angles. The analysis is performed for two types of sheet pile walls having different flexibilities. The driven depth of the wall is taken 1.25 times the free height of the wall. The shape factors, which describe the dimensions of the berm, are the top width, height of berm and slope of berm. These shape factors are varied to study the effect of each paramater on the behaviour of the system.

The finite element program (PLAXIS) is used to estimate the effect of berm on the stability and deflection of the wall in cohesionless soils. The results obtained from the limit equilibrium and analytical methods are verified by laboratory model. Final charts are prepared for the reduction in the deflection and moment due to presence of stabilizing berm.

Computer programs written in FORTRAN77 code were prepared for graphical solution and approximate methods. The results from approximate methods are compared with results from graphical and analytical solutions. The results obtained from approximate methods are not in agreement with those calculated with graphical analysis (trial wedge analysis). The approximate methods give higher values of

bending moment on the sheet pile walls. The results obtained from analytical methods show that the moment on the wall is less than the moment from limit equilibrium analysis.

Tests on the cantilever sheet pile model show that the results from the analytical analysis are the most accurate for the problem of interest in this research. All methods of analysis indicate that the use of a berm has a significant effect on reducing moment and deflection. This has an obvious economic concequence in that smaller cross sections may be used in the earth retaining structures.

CHAPTER (1)

INTRODUCTION

It is common practice in the construction of a wide excavation supported by a temporary wall to leave a slopping earth berm against the wall. The berm increases the passive earth pressure acting on the embedded part of the wall because the passive pressure is a function of the vertical soil pressure acting on the potential failure zone near the wall. This can be increased significantly by leaving a berm against the foot of the wall at the dredged level. This is due to the fact that in retaining wall design the temporary condition during construction is often more critical than the permanent condition, and the berm can often be accommodated at a reasonable cost in that condition. Berms offer a valuable means of minimizing cost in certain instances. The berm is designed to serve as a restraint, which stabilizes the wall and soil movements. Damage to a bermed wall system can occur as a result of development of insufficient passive resistance by the berm or a slope failure in the berm. These problems can result in a total system collapse, but more commonly lead to large deformations that result in damages to adjacent structures.

There are various ways in which the effects of berms can be assessed. It would, in theory, be possible to analyze the passive failure mechanism for the wall including the berm, by an iterative method involving a series of trials with an appropriate failure mechanism. Culmman's graphical method can be used to evaluate the passive resistance of the berm. Several approximate methods are used in practice as indicated in section (2-5). All previous methods have some shortcomings as detailed in the following Chapters. In addition, evaluating the effect of berm size and strength in limiting deformations can not be obtained from these methods.

Analytical studies of the bermed wall system are performed using the finite element program (PLAXIS). The study is made for cohesionless soils with different properties. The hardening soil model is used in this research . The description of this model is introduced in Chapter (3). The results of the analyses are introduced in simple charts to be used easily in every day design. From the charts, the moment and deflection factors can be obtained for a certain angle of friction and berm to wall height ratio.

The moment factor is the ratio between maximum moment developed in a wall with a berm and the moment developed in a wall without berm. The deflection factor is the ratio between deflection developed in the wall with a berm and deflection developed in the wall without berm. The finite element analyses are done for different soils with different friction angles. Results for one soil group are included in Chapter (4). The results for other soil groups are summarized in the attached appendices.

The finite element results are compared with the limit equilibrium analysis using graphical and approximate methods. Computer programs in Fortran77 code are written to simplify the use of limit equilibrium analysis. These programs are done to perform the analysis of the cantilever sheet pile wall utilizing UK and USA methods. One of these programs uses the trail wedge method in the analysis. Other programs use the approximate methods to evaluate the effect of the berm but the straining actions are calculated using USA and UK methods.

To verify the results of finite element analysis, experimental tests are made on a sheet pile model in the laboratory. The results of the model are compared with those of the finite element.

CHAPTER (2)

LITERTURE REVIEW

2.1.General

The analysis of cantilever sheet pile walls with stabilizing berm consists of two steps. First, evaluation of the active and passive earth pressure forces on the sheet pile wall. Second, determination of the driven depth required for the stability of the wall. The active earth pressure forces may be evaluated from Rankine's or Coulomb's earth pressure theories. The evaluation of passive earth pressure is more complicated than the active earth pressure due to the existance of the berm. The passive earth pressure can be evaluated from Culmann’s graphical method or by an iterative method involving a series of trials with an appropriate plastic failure mechanism, but this would lead to a protracted method and would be inconvient in every day design. In addition, these methods do not assign the distribution of the earth pressure or the point of application of the total earth pressure force. For these reasons, different approximate methods are stated to evaluate the passive earth pressure as given by Fleming (1985) and by the Naval Facilities Engineering Command (1982).

Several methods for analysis and design of embedded cantilever walls have been proposed. Bica & Clayton (1989) reviewed these methods. Each method takes various assumptions into consideration concerning the distribution of earth pressure on the wall and the deflection or the wall movement. The common methods for the analysis of the cantilever walls are the UK method given by Padfield and Mair (1984) and USA method proposed by Krey (1932).

The UK and USA methods are limit equilibrium methods based on the classical limiting earth pressure distributions. In the last few years the finite element approach has been widely used in the analysis of sheet pile walls. These methods give the actual earth pressure distribution and the deflection of every point on the wall.

2.2. Earth Pressure Theories

These theories deal with the magnitude and distribution of lateral earth pressure between soil and adjoining structures. All of these theories assume plane strain conditions and depend on the theory of plasticity. The exact analysis of lateral earth pressure problems is very complex because it requires knowledge of appropriate equations defining the stress-strain relationships and boundary conditions. This analysis may be performed using the concept of plastic failure, which is more convenient for this problem. The plastic collapse occurs after the state of plastic equilibrium has been reached in a part of the soil mass, resulting in the formation of an unstable mechanism. Coulomb stated his theory in 1776, which depends on the concept of plastic failure. This theory considered the stability of a soil wedge between the retaining structure and a trial failure plane. Coulomb's wedge is in a condition of plastic equilibrium. In 1857, Rankine considered the state of stress in a soil mass when the condition of plastic equilibrium has been reached. Other methods also depending on the concept of plastic equilibrium are proposed by Culmann (1886), Rebhann (1871).

2.2.1. Rankine's Earth Pressure Theory

Rankine (1857) considered the equilibrium of a soil element within a soil mass bounded by a plane surface. Rankine made the following assumptions for the derivation of earth pressure:

1. The soil mass is homogeneous and semi-infinite.
2. The soil is dry and cohesionless.
3. The ground surface is plane.
4. The back of the wall is smooth and vertical.

Rankine stated that active and passive earth pressure coefficients are:

$$Ka = \frac{1-\sin\varphi}{1+\sin\varphi} \qquad (2\text{-}1)$$

$$Kp = \frac{1+\sin\varphi}{1-\sin\varphi} \qquad (2\text{-}2)$$

When the back fill of the wall is inclined at an angle i, with the horizontal, Rankine stated that the active and passive earth coefficients are:

$$Ka = \cos i \frac{\cos i - \sqrt{\cos^2 i - \cos^2 \varphi}}{\cos i + \sqrt{\cos^2 i - \cos^2 \varphi}} \qquad (2\text{-}3)$$

$$Kp = \cos i \frac{\cos i + \sqrt{\cos^2 i - \cos^2 \varphi}}{\cos i - \sqrt{\cos^2 i - \cos^2 \varphi}} \qquad (2\text{-}4)$$

2.2.2. Coulomb's Earth Pressure Theory

Coulomb (1776) developed a method for determination of the earth pressure in which he considered the equilibrium of the sliding wedge, which is formed with the movement of the retaining wall. Coulomb made the following assumptions:

1. The soil is homogeneous, isotropic and ideally plastic material.
2. The slip surface is plane surface.
3. The back surface of the wall is rough.
4. The sliding wedge itself acts as a rigid body.

Coulomb stated that the active and passive earth pressure coefficients are:

$$Ka = \frac{\sin^2(\beta + \varphi)}{\sin^2(\beta)\sin(\beta - \delta)\left[1 + \sqrt{\frac{\sin(\varphi + \delta)\sin(\varphi - i)}{\sin(\beta - \delta)\sin(\beta + i)}}\right]^2} \qquad (2\text{-}5)$$

$$Kp = \frac{\sin^2(\beta + \varphi)}{\sin^2(\beta)\sin(\beta - \delta)\left[1 + \sqrt{\frac{\sin(\varphi + \delta)\sin(\varphi - i)}{\sin(\beta - \delta)\sin(\beta + i)}}\right]^2} \qquad (2\text{-}6)$$

2.2.3. Culmann's Method

Culmann (1866) developed a graphical procedure for evaluating the lateral earth pressure for granular soil. This method may be used to determine the passive resistance of the stabilizing berm as stated by the design manual of Naval Facilities Engineering Command. It stated the following steps to calculate the passive resistance as in Figure (2.1):

1. Draw the berm to scale.
2. Layout OX from point O at angle φ below horizontal.
3. Layout OY from point O at angle $(\alpha+\delta)$ below OX.

4. Assume failure surfaces originating at point O and passing through points a, b, c, etc.
5. Compute the weight of each failure wedge.
6. Layout the weight of each failure wedges along OX to a convenient scale.
7. Draw a line parallel to OY for each failure wedge from its weight plotted on OX to its failure plane (extrapolated where necessary).
8. Connect the intersecting points from 7 above with a smooth curve. Draw a tangent to this curve which is also parallel to OX.
9. Through the tangent point F, draw a line parallel to OY to intersect OX at Wf. Distance FW_f is the value of Pp in the weight scale.
10. Normal component of the passive resistance, $P_N = P_p \cos\delta$.
11. To compute pressure distribution on the wall, assume a triangular distribution.

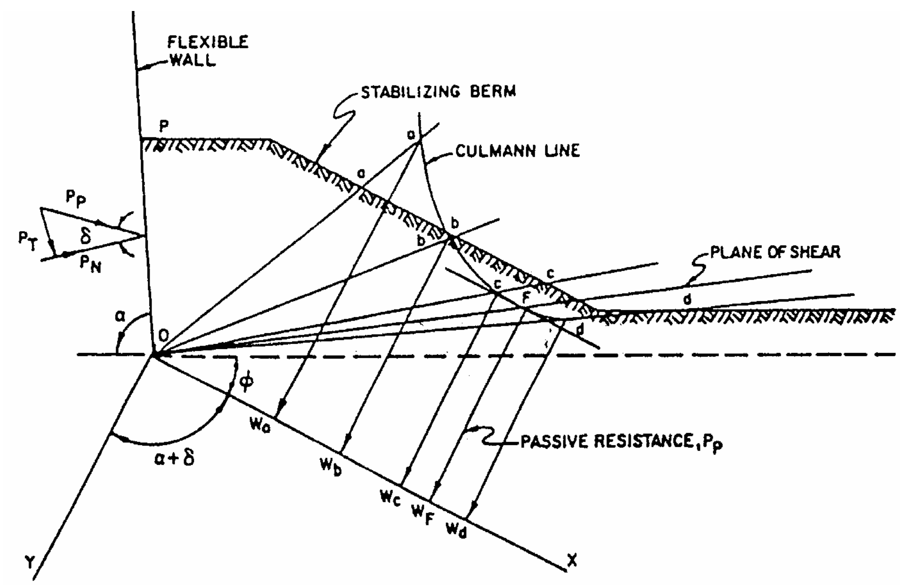


Figure: (2.1) Culmann method for determining earth pressure of earth berm (Granular soil)

2.3. Analysis of cantilever Sheet Pile Walls

There are two different approaches for the analysis of cantilever sheet pile walls. The limit equilibrium approach depends on estimating the limiting earth pressure coefficients from plastic theories and these values are used to calculate the earth pressure forces on the wall. The equilibrium equations are used to deduce the driven depth of the wall in the limit equilibrium condition. This depth is increased by a certain factor of safety to limit the movement of the wall and to take into consideration the errors in soil parameters and analysis theories.

The second approach is the analytical methods first proposed by Morgenstern and Eisenstein, (1970). This method is developed by Clough and Duncan in (1971). The analytical methods often use the finite element technique to solve the stiffness equations. The analytical approach requires good knowledge of the stress-strain behaviour of the soil and the parameters, which describe the soil and structure behaviour.

2.3.1. Limit Equilibrium Analysis

The basis of the limit equilibrium methods is the prediction of the maximum height of the excavation for which static equilibrium is maintained. This is known as the limiting equilibrium situation. It is therefore important to be able to accurately evaluate the earth pressure acting on each side of the wall in the limiting equilibrium condition. The actual distribution and magnitude of earth pressure on an embedded retaining wall is dependent on the complex interaction of the wall and the soil. The general shape of the earth pressure is shown in Figure (2.2). The common limit equilibrium design and analysis methods are all based on this general shape. Each method makes different simplifications and assumptions that modify the general shape of the pressure distribution to enable a solution to be found.

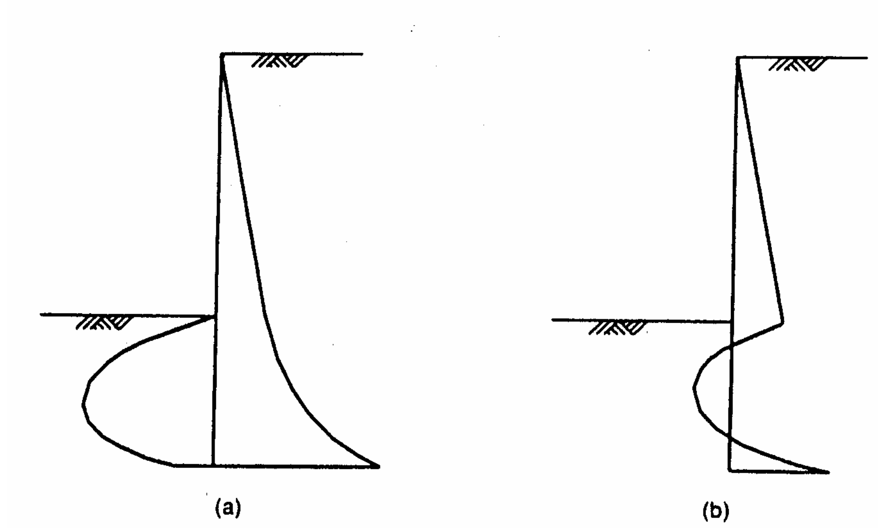


Figure (2.2): Earth Pressure on Cantilever Wall
(a) Actual Pressure Distribution (b) Net Pressure Distribution

2.3.1.1. UK Method

In this method the earth pressure distribution is simplified as shown in Figure (2.3). The lines marked Ka and Kp indicate the active and passive limiting equilibrium pressure values defined by the earth pressure coefficients Ka and Kp. The force R, representing the net force acting below point o, is assumed to act at point o. Moment equilibrium about o, yields the value, d_o required for stability. The penetration depth, d, is then taken as $1.2d_o$. Finally, a check is made to ensure that the force ,R can be mobilized on the wall below point, o. The bending moment diagram is calculated from the assumed pressure distribution. This method is commonly used in the UK. It is described by Padfield and Mair, (1984).

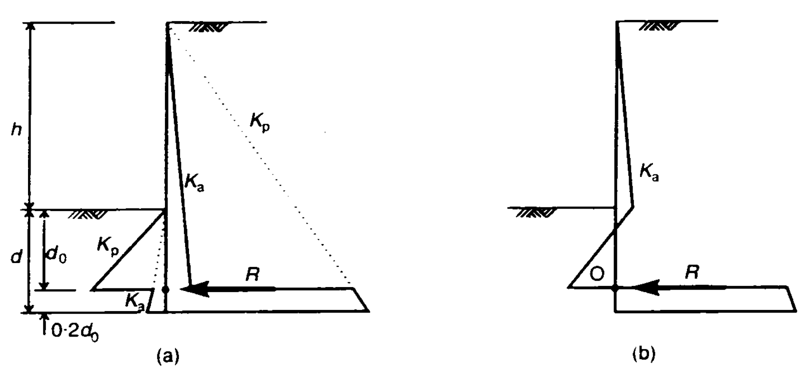


Figure (2.3): Simplified Earth Pressure Distribution – UK Method
(a) Actual Pressure Distribution (b) Net Pressure Distribution

2.3.1.2. USA Method

In this method, the earth pressure distribution is simplified by the rectilinear distribution shown in Figure (2.4). The rectilinear distribution is characterized by the parameters P_a, P_1, P_2 and y. This is a modern version of a method initially proposed by Krey, (1932). It is described by Bowles, (1988) and King, (1995). This method is commonly used in the USA. It is reasonable to assume that the pressure behind the wall at the dredge level, P_a, is equal to the active pressure limit. Hence, there are four unknown values, d, P_1, P_2, y, which need to be determined. The consideration of horizontal force and moment equilibrium provides two equations. In order to obtain a solution, two more assumptions are necessary. In the USA method these assumptions are as follows:

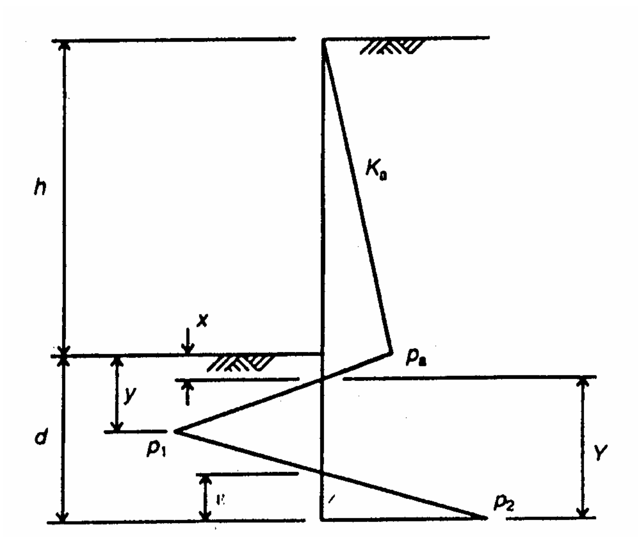


Figure (2.4): Rectilinear Earth Pressure Distribution

a) The limiting passive pressure is fully mobilized on the wall immediately below dredge level. This assumption gives the gradient of the rectilinear pressure distribution between P_a and P_1. It is equal to the passive pressure gradient minus the active pressure gradient, γ (K_p - K_a), where γ is the unit weight of the soil.

b) The value of P_2 is equal to the passive pressure limit on the retained side minus the active pressure on the dredged side. This is the maximum possible value, which P_2 can have:

$$P_2 = \gamma(h+d)K_p - \gamma dK_a \qquad (2\text{-}7)$$

The equations of equilibrium and constraints imposed by the two assumptions yield the limiting equilibrium depth of penetration, d.

2.3.2. Numerical Analysis

Full analysis of soil and structure stiffness and their interaction using realistic soil constittutive models and accurate boudary conditions has been possible for some years. The principal advantages of such an approach include the ability to model wall and soil deformation and stresses in a realistic sequence of operations that follow actual construction stages. As computer technology progresses, the application of these methods to the soil problems become more universal. Many researchers have written computer programes for the anlysise of soil- structure interaction problems, Shaarawi,(1980)

2.4. Allowable Deflection of Cantilever Walls

In the late 1920s and early 1930s Karl Terzaghi, reported the results of a series of experiments on large-scale model retaining walls. Figure (2.5) summarizes the results of Terzaghi's findings. From the figure, it could be seen that larger displacements are required to develop the passive state of stress than to develop the active state. Generally limiting states are states of failure. From the figure it can be seen that a soil wedge develops upon reaching the limiting equilibrium states. The wedge on the passive side is larger in volume than the wedge on the active side. The soil in both wedges is compressible. Therefore, in the passive case, more wall displacement is required before the ultimate shear stress is reached. So in practice, in order to limit wall movement, it would be necessary to apply higher factors of safety, of the order of 1.5 - 2.0, on the passive shear strength.

Rowe and Peaker, (1951) consider that, a horizontal movement at the top of the wall of the order 5% of wall height would represent the limit of acceptability. Consequently, they determined experimentally the actual values of the developed passive resistance. Table (2.1) compares the values of the passive earth-pressure coefficient at ultimate shear conditions with those recommended by Rowe and

Peaker. It can be seen that in loose sand deposits, for acceptable wall movements, normally a factor of safety of about 1.5 is recommended with respect to the passive earth pressure. For loose sand, ultimate passive pressure occurs for wall movements between 25% and 40% of the wall height. For dense sand, movements at ultimate passive resistance are equal to approximately 5% of the wall height.

δ	Passive Earth Pressure Coefficients, Kp		Ratio
	Full Shear Condition (1)	For Acceptable Wall Movement (2)	(1)/(2)
0	3.4	2.5	1.40
10	4.5	3.0	1.50
20	5.6	3.6	1.60
30	6.7	4.3	1.6

Table (2.1): Comparison of Theoretical Passive Earth Pressure Coefficient Values with those Recommended by Rowe and Peaker

Note: results for loose sand, φ=33 degree and vertical wall with horizontal surface to backfill

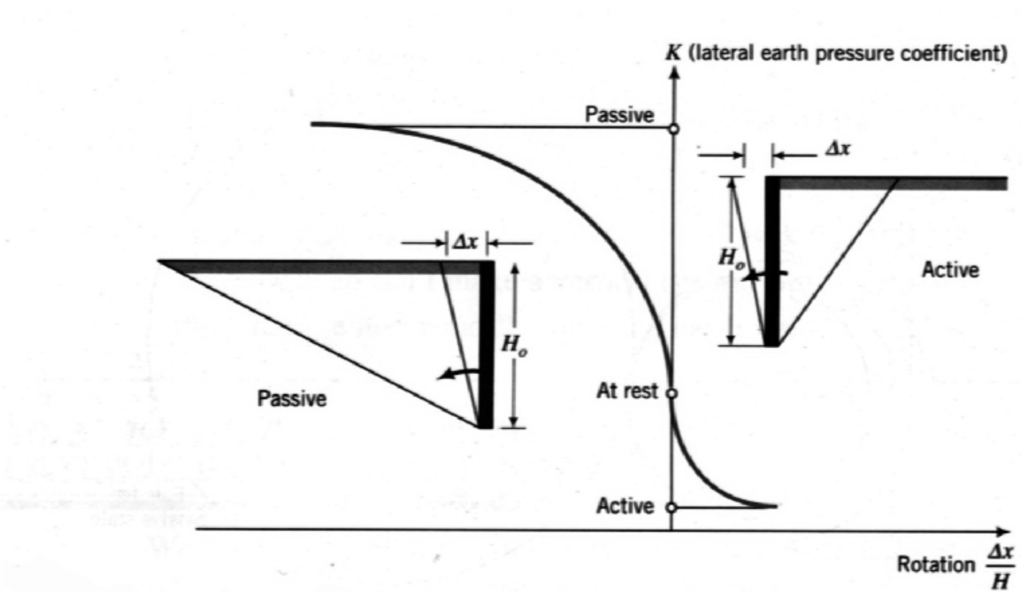


Figure (2.5): Effect of Wall Movement on Earth Pressure

2.5. Approximate Methods for Considering Berm Effects

There are different approximate ways in which the effects of berms can be assessed. The berm is treated as either effective surcharge applied at the final excavation level or as an increase in the original ground level on the passive side of the wall as indicated by Fleming et al., (1985).

2.5.1. First Method

An empirical method is to treat the berm as causing an increase in the effective ground level on the passive side of the wall. In this method the height of the berm is treated as not more than 1/3 x berm width as shown in Figure (2.6), and the effective ground level is then taken as half of the height of the berm at the point where it contacts the wall. Any stable soil existing above the 1:3 slope may be then treated as a surcharge acting on the effective ground surface over the approximate width of the potential passive failure mechanism. While this method is highly empirical, it appears to yield relatively satisfactory and conservative results compared with other methods, both in terms of wall depth and bending moment.

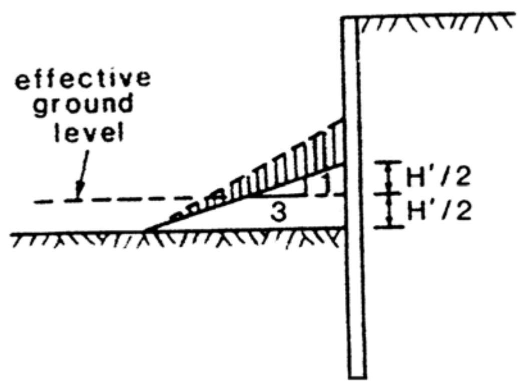


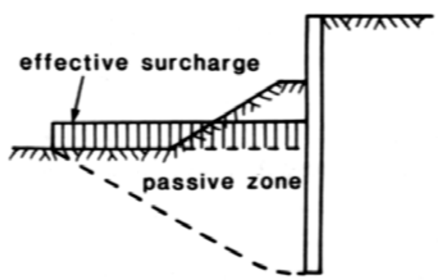
Figure (2.6): Relation of Effective Ground Level to Berm Dimensions

2.5.2. Second Method

In this method, the berm is converted to effective surcharge acting on the potential failure zone. The effective self-weight of the berm is calculated and is then distributed over the approximate width of the passive failure mechanism at the general final site excavation level as in Figure (2.7) thus increasing the passive pressure available accordingly. In addition to the enhanced passive pressure, some shear forces must exist in the berm above the dredge level and these will contribute to the stability and to moment reduction in the wall. If the shear forces acting within the berm are not taken into account, and it is perhaps difficult to do so reliably because of softening of the material involved in the berm, then this method must be regarded as conservative.

Figure (2.7): Treatment of Berm as Surcharge

2.5.3. Third Method (Naval Department Method)



An approximate method of analysis is to replace the berm with an equivalent sloping plane, and assign an appropriate passive pressure coefficient from Rankine's earth pressure theory as mentioned in Section (2.2.1). For further details refer to NAVFAC.

2.6. Finite Element Analysis for Wall with Stablizing Berm

A parametric study of a typical sheet pile wall with stablizing berm with 5m total height is performed by Georgiads and Anagnostopoulos, (1998). The analysis is made using the PLAXIS program and the soil is considered as a linearly elastic perfectly plastic material. The analysis is made for a soil having a friction angle,φ, of 42°, a dry unit weight of 15.5kN/m^3, a Young's modulus of 20kPa and Poisson's ratio of 0.20. Interface element with δ=0.50φ is used between the soil and adjoining wall. Tests were performed on a laboratory model cantilever wall. The measured values from the model are reported to be in agreement with values predicted from the finite element analysis.

CHAPTER (3)

FINITE ELEMENT ANALYSIS

3.1. Introduction

The finite element method is one of the most powerful approximate solution methods that can be applied to solve a wide range of problems represented by ordinary or partial differential equations. The power of such a method derives from the fact that it can easily accommodate changes in the material stiffness, which is evaluated at element level. In addition, it allows different boundary conditions to be applied. The finite element procedure consists of the following steps:

1. Discretisation and selection of elements.
2. Selection of stress-strain relationships.
3. Evaluation of element matrices.
4. Assembly of element matrices and introduction of boundary condition.
5. Solution of nodal unknowns.
6. Computation of derived quantities, and analysis of results.

3.2. Program Used in Analysis (PLAXIS)

The program used in this analysis is called (PLAXIS) prepared by Technical University of Delft, (1987). The direct support for the program is obtained from the following centers of research:

Delft University of Technology

Institut fur Geotechnik, Uni Stuuttgart

Laboratotoire 3s, Univ. of Grnoble

University of Oxoford

University of Colorado

Norwegian University of Science and Technology

Massachusetts Institute of Technology

Technical University Graz

PLAXIS is a finite element program that has been developed specifically for the analysis of deformation and stability in geotechnical engineering problems.

3.3. Description of the Finite Element Model Used in Analysis

A plane strain model is used for the analysis of structures with uniform cross section and corresponding stress state and loading scheme over a certain length perpendicular to the cross section is assumed to be zero. Thus, this model is very accurate and suitable to simulate the retaining structure with stabilizing berm. This model includes main elements such as soil elements, beam elements and interface elements.

3.3.1 Components of the Model

In this section a more detailed description of the elements used in the model is presented. As stated above elements representing soil, wall, and interface are the main components of the model. Their properties are detailed below.

3.3.1.1 Soil Elements

The program includes two types of elements, 6-node and 15-node triangular elements. The 15-node triangular elements give higher accuracy than 6-node element, because it involves 12 stress points and it provides a fourth order interpolation for the displacement. The 15-node element has been shown to produce high quality stress results for difficult problems as for example in collapse calculations for incompressible soils as introduced by Nagtegall, J.C (1974). Thus, the 15-node element is used in the analysis.

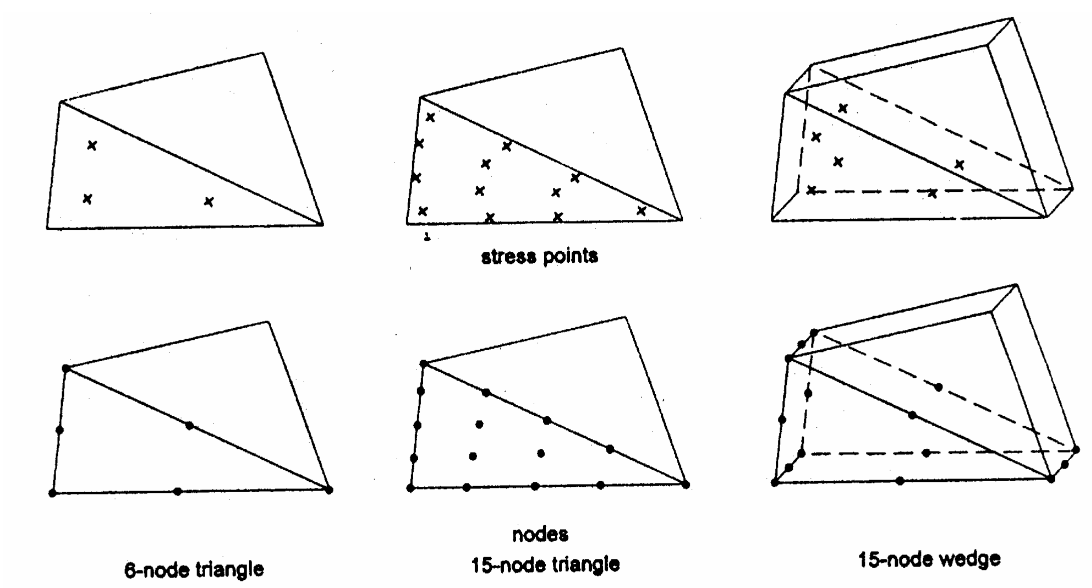


Figure (3.1): Position of Nodes and Stress Points in Soil Elements

3.3.1.2. Beam Elements

Beam elements are used to model the retaining structure. Although beam elements are actually one-dimensional elements, the beams represent real plates in the out-of plane direction and can therefore be used to model the retaining structure such as diaphragm and sheet pile walls. The 5-node beam elements are used to be compatible with the 15-node triangular elements used to modeling the soil. The positions of nodes and stress points in a 5-node beam element are shown in Figure (3.2). The parameters used to define the beam element are the flexural rigidity, (EA), axial stiffness, (EI), Poisson's ratio, (ν) and the weight per unit area, (w). The values used for these parameters are introduced in Section (3.2). Bending moments on beam elements are evaluated from the stresses at the stress points.

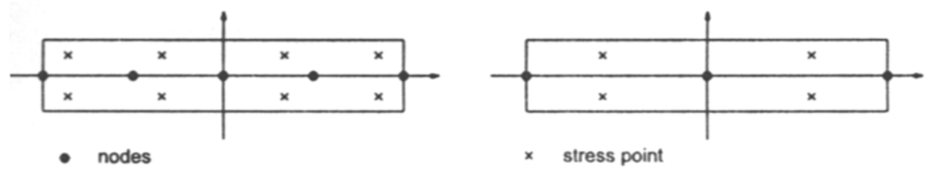


Figure (3.2): Position of Nodes and Stress Points
in a 3-node and 5-node Beam Element

3.3.1.3. Interface Elements

The interface elements are used to model the interaction between the retaining structure and the soil. The interfaces are placed at both sides of the structure. The roughness of the interaction is modeled by choosing a suitable value for the strength reduction factor. This factor relates the wall friction and adhesion to the friction and cohesion of the soil. The interface elements are defined by 5-pairs of nodes to connect between the soil element and beam elements. Figure (3.3) shows how interface elements connected to the soil elements. The interface elements have zero thickness. The properties of the interface element are linked to the strength of the soil through the strength reduction factor. The values used in the analysis for the strength reduction factor are introduced in Section (4.3).

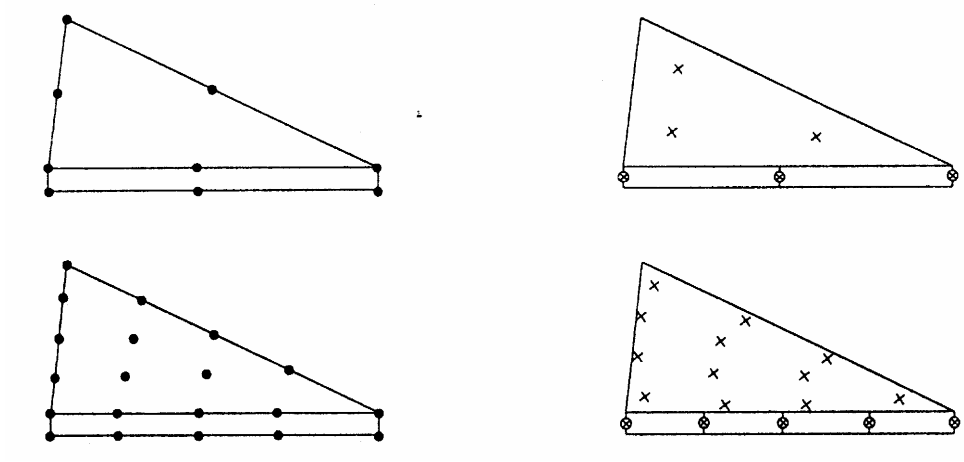


Figure (3.3): Distribution of Nodes and Stress Points in Interface Elements and Connection with Soil Elements

3.4. Modeling of Soil Behavior

Soil tends to behave in a highly nonlinear way under loads. This nonlinear stress-strain behavior can be modeled to various levels of accuracy. There are different models to simulate the soil behavior such as the linear elastic model, elastic perfectly plastic model, Mohr-Coloumb model, hardening soil model and soft soil model. The hardening soil model is an advanced model for simulating the different types of soil, both soft and stiff soils, Schanz (1998). When soil is subjected to a primary deviatoric stress loading, it shows a decreasing stiffness and simultaneously irreversible plastic strains develop. In the special case of drained triaxial test, the observed relationship between the axial strain and deviatoric stress may be approximated by a hyperbola. Such a relationship was first formulated by Kondner, (1963) and later used in the well-known hyperbolic model, Duncan and Chang,(1970). The basic feature of the hardening-soil model is the stress dependency of soil-stiffness.

3.4.1. Hyperbolic Relationship for the Hardening Soil Model

The basic idea for the formulation of the hardening soil model is the hyperbolic relationship between the vertical strain ε, and the deviatoric stress, q. this relationship can be described by:

$$-\varepsilon = \frac{1}{2E_{50}} * \frac{q}{(1-q/q_a)} \qquad \text{For } q < q_a \qquad (3\text{-}1)$$

Where:

q_a : The asymptotic value of the shear strength.

E_{50}: The confining stress dependent stiffness modulus.

This relationship is plotted in Figure (3.4). The confining stress dependent stiffness modulus for primary loading and is given by the equation:

$$E_{50} = E_{50}^{ref} * \left(\frac{c\cot\varphi - \sigma_3^{'}}{c\cot\varphi + p^{ref}} \right)^m \qquad (3\text{-}2)$$

Where:

E_{50}^{ref} : The reference stiffness modulus.

p^{ref} : The reference confining pressure.

$\sigma_3^{'}$: The confining pressure in the triaxial test.

The reference stiffness modulus is corresponding to the reference confining pressure, p^{ref}, The actual stiffness depends on the minor principal stress, σ_3, which is the confining pressure in the triaxial test. The amount of stress dependency is given by the power, m. The power m takes values between 0.50 and 1.00 as indicated by Von Soos, (1990). The ultimate deviatoric stress, q_f and the quantity q_a in Equation (3-1) are defined as:

$$q_f = \left(c\cot\varphi - \sigma_3^{'}\right) * \frac{2\sin\varphi}{1-\sin\varphi} \qquad (3\text{-}3)$$

$$q_a = q_f / R_f \qquad (3\text{-}4)$$

The ratio between q_f and q_a is given by the failure ratio R_f, that should be smaller than unity. From previous research the value 0.90 is considered a suitable value for all soils. For unloading and reloading stress paths, another stress-dependent stiffness modulus is used:

$$E_{ur} = E_{ur}^{ref} * \left(\frac{c\cot\varphi - \sigma_3^{'}}{c\cot\varphi + p^{ref}} \right)^m \qquad (3\text{-}5)$$

Where:

E_{ur}^{ref} : The reference Young's modulus for unloading and reloading corresponding to the reference pressure, p^{ref}.

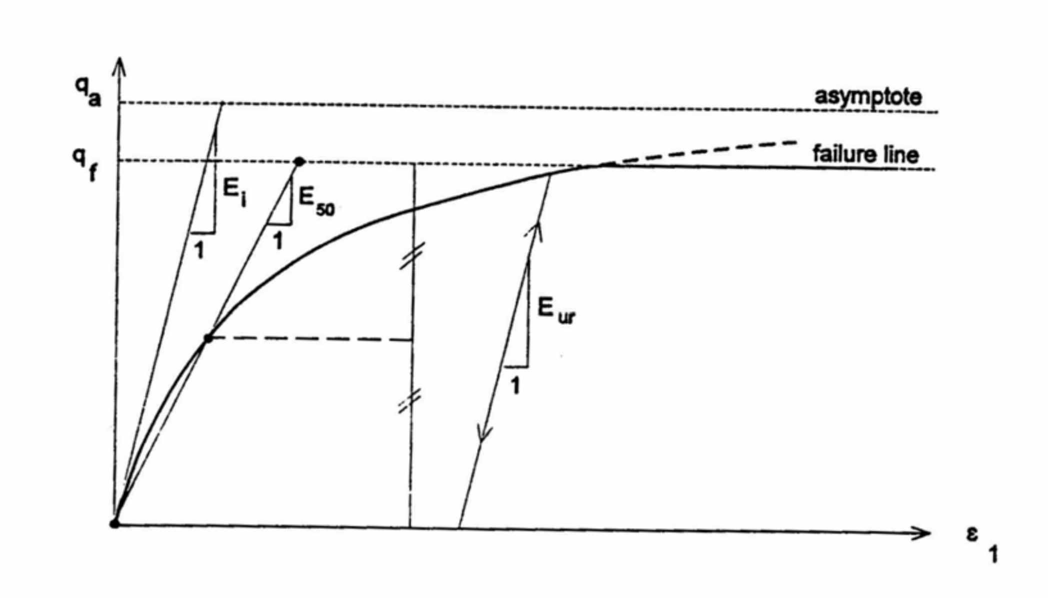


Figure (3.4): Hyperbolic Stress-Strain Relation in Primary Loading for Standard Drained Triaxial Test

3.4.2. Parameters of Hardening Soil Model

The parameters used for defining the hardening soil model may be divided into two groups. The failure parameters group includes effective cohesion, effective angle of friction and the angle of dilatancy. The stiffness soil group includes the secant stiffness modulus in the triaxial test, the tangent stiffness modulus for the primary oedometer loading and the power for stress-level dependency of stiffness.

3.4.2.1. Effective Angle of Friction

The friction angle φ, determines the shear strength of the soil as shown in Figure (3.5) and also determine the yield surface of the soil as in Figure (3.6). The angle of friction used in the analysis may be obtained from the triaxial test or from the shear box test. When the laboratory tests are not conducted, the angle of friction may be correlated from equations (3-6) to (3-8) as given by Boweles, (1988).

$$\varphi = \sqrt{18N} + 15 \qquad (3\text{-}6)$$

$$\varphi = 0.36N + 27 \qquad (3\text{-}7)$$

$$\varphi = 4.50N + 20 \qquad (3\text{-}8)$$

The Egyptian Code of Practice gives correlation for friction angle with SPT number as indicated in Table (3.1).

SPT number (N)	Description	Angle of friction (φ)
0 – 4	Very loose sand	27 – 30
4 – 10	Loose sand	30 – 32
10 – 30	Medium sand	32 – 36
30 – 50	Dense sand	36 – 40
> 50	Very dense sand	> 40

Table (3.1) : Correlation for the Friction Angle with SPT number

Where:

φ : The angle of internal friction.

N : The standard penetration number (SPT).

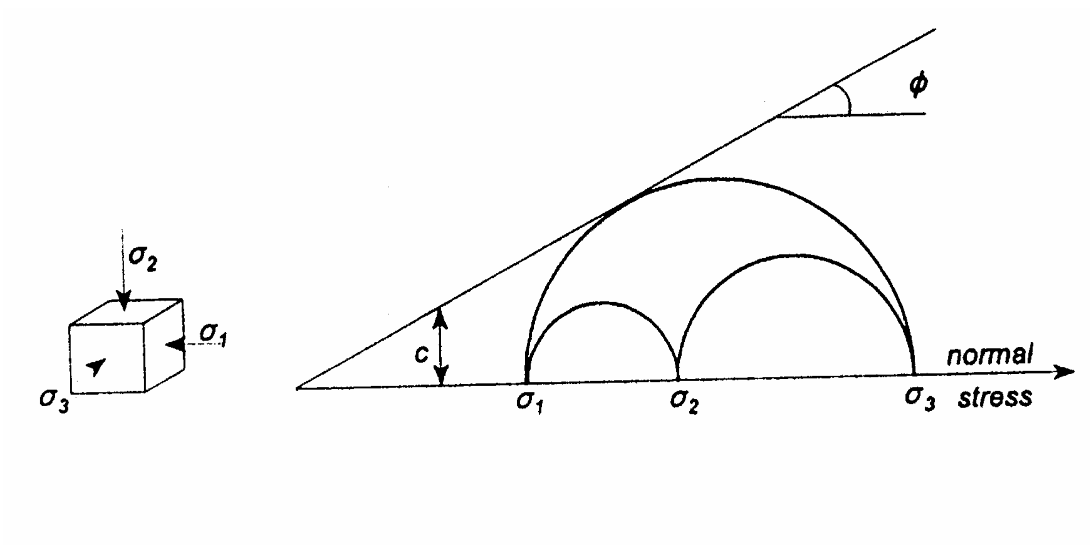


Figure (3.5) Stress Circles at Yield; One Touches Coulomb's Envelope

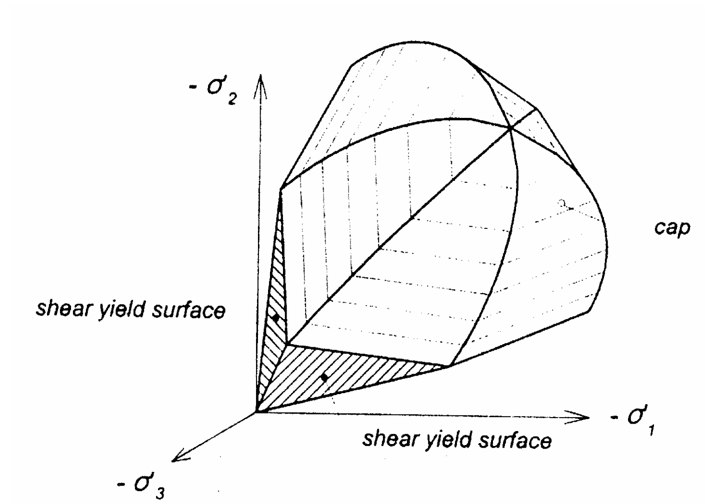


Figure (3.6): Representation of Total Yield Contour of Hardening Soil-Model in Principal Stress Space for Cohesionless Soil

3.4.2.2. Dilatancy Angle

The dilatancy of sand depends on both the density and on the friction angle. The angle of dilatancy may be estimated as indicated by Bolton (1986).

$$\psi = \varphi - 30 \qquad \text{For } \varphi > 30° \qquad (3\text{-}9)$$

For φ-values of less than 30°, the angle of dilatancy is mostly zero.

3.4.2.3. Stiffness Modulus

The stiffness modulus, in general, refers to the relation between the stress and strain. The stress-strain behavior of soil is very complex. The amount of strain caused by a stress increment is a function of a number of factors such as the composition, void ratio, past stress history of soil and the mode of stress application.

The stiffness modulus can be obtained from the triaxial test or from the oedometer test. When the laboratory tests are not conducted the stiffness modulus may be obtained from the following correlations:

1. Denver (1982) gave the following parabolic correlation between N and drained Young's modulus:

$$E = 7\,N^{0.5} \text{ Mpa} \qquad (3\text{-}10)$$

2. Webb (1970) stated that the relationship between N values and the drained Young's modulus can be approximated by:

$$E = aN+b \qquad (3\text{-}11)$$

2. Bowles (1982) proposed the following correlation between N values and the drained Young's modulus:

$$E=50(N+15)\ t/m^2 \qquad (3\text{-}12)$$

3. Schmertman (1980) proposed the following correlation:

$$E=10N\ kg/cm^2 \qquad (3\text{-}13)$$

The Egyptian Code of Practice gives values for the deformation modulus with the relative density of cohesionless soil. Table (3.2) presents this correlation.

Description	Deformation modulus(kg/cm^2)
Loose sand	100 - 250
Medium sand	250 –750
Dense sand	750 – 1500
Very dense sand	1500 – 4000
Gravel	1000 – 4000

Table (3.2): The Deformation Modulus for Cohesionless from E.C.P.

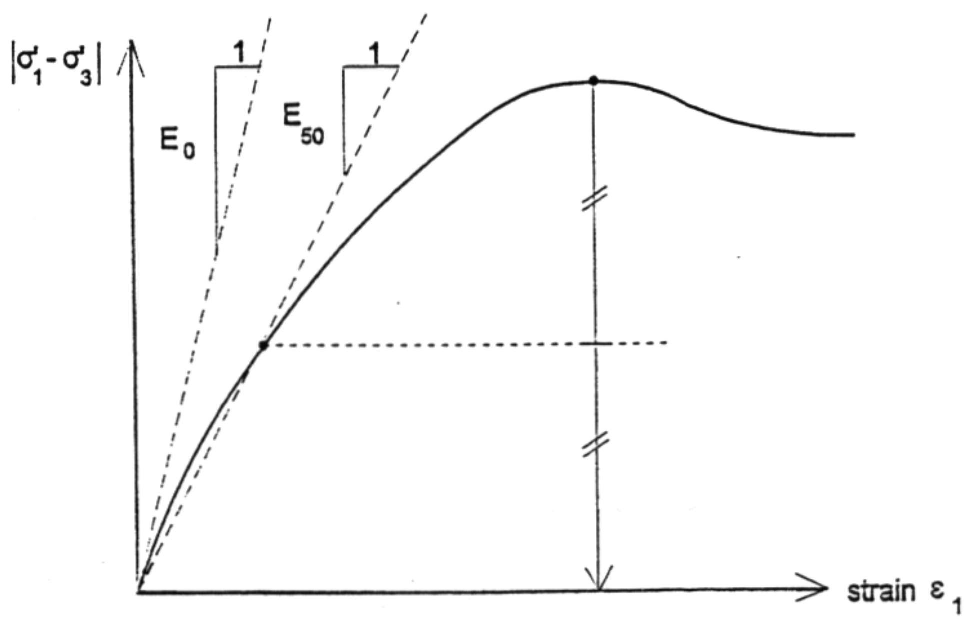


Figure (3.7): Definition of Tangent and Secant Deformation Modulus

3.4.2.4. Strength Reduction Factor

The strength properties of interfaces are linked to the strength properties of soil by the strength reduction factor. In general, real soil-structure interaction, the interface is weaker and more flexible than the associated soil. The strength reduction factor depends on the soil and roughness of the structure. This factor can be obtained from the shear box test, a piece of the structure material is put in the lower part of the box and the upper part is filled with the soil. The determination of the factor usually estimated from the values given in previous research or soil mechanics codes. The Egyptian Code of Practice gives the maximum values for the angle of friction between soil and wall and the maximum values for the friction factor as in Table (3.3).

Type of Wall and Soil	Friction Factor	Angle of Friction
a- Retaining Wall		
- Gravel, sandy gravel, coarse sand	0.55 – 0.60	29 – 31
- Fine to medium sand	0.45 – 0.55	24 – 29
- Fine sand	0.35 – 0.45	19 – 24
b- Diaphragm Wall		
- Gravel, sandy gravel	0.40 – 0.50	22 – 26
- Sand	0.30 – 0.40	17 – 22
c- Steel Sheet Pile		
- Gravel, sandy gravel	0.40	22
- Sand	0.30	17

Table (3.3): The Maximum Angle of Friction between Soil and Wall from E.C.P

3.4.3. Configuration of the Finite Element Mesh

The properties of the finite element mesh affect the accuracy of the results, thus these properties must be selected to give the most accurate results possible from the program. These properties include the dimension and the coarseness of the mesh.

3.4.3.1. Dimensions of the Finite Element Mesh

A finite element mesh related to a given problem in geomechancis must always have dimensions that are sufficient for representing the problem. The boundary of the mesh must be far enough to avoid its effect on the results of the analysis. For the analysis of the diaphragm and sheet pile walls, the dimensions of the mesh must be taken as in Figure (3.8) as given by Aziz, F., (1999).

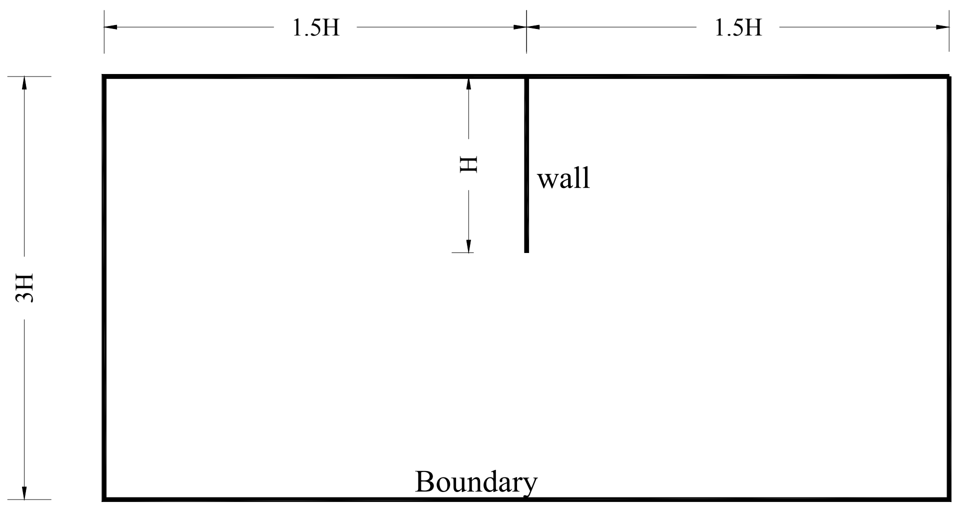


Figure (3.8) : Typical mesh dimensions for sheet pile wall

3.4.3.2. Coarseness of the Finite Element Mesh

The program allows for a fully automatic generation of the finite element mesh. The mesh generator is a special version of the triangular mesh generator developed by Sepra. The generation process is based on the Robust triangulation principle that searches for optimized triangular distibution of elements and which results in an unstructured mesh. Unstructured meshes are not formed from regular patterns of elements. The numerical performance of these meshes however, is usually better than the structured meshes with regular array of elements.

The number of elements of the mesh depend on the degree of coarseness of the mesh and the its dimensions. Increasing the refinement of the mesh improves the results of the analysis but this requires more time and more powerful computers. The program includes five degree of coarseness as in Table (3.4).

Degree of coarseness	Approximate number of elements
Very coarse	50
Coarse	100
Medium	250
Fine	500
Very fine	1000

Table (3.4): The Degree of Coarseness of Mesh and Corresponding Number of Elements

3.4.4. Initial Stresses in the Finite Element Model

One of the most important steps in the analysis is the determination of the initial stresses in the soil domain. The initial stresses include two parts, the initial pore water pressure and the initial effective stress. The initial pore water pressure is zero because the soil in analysis is considered to be dry. The effective stresses include the vertical and lateral stresses. The vertical effective stresses are calculated from the dry density of the soil and depth of the point below the ground surface. The lateral stresses are characterized by the vertical stresses, σv, that is related by the coefficient of at rest lateral earth pressure, Ko. The at rest earth pressure coefficient is based on Jaky's formula (3-14)

$$Ko = 1 - \sin(\phi) \qquad (3\text{-}14)$$

Where:

Ko = At rest earth pressure coefficient.

ϕ = Angle of shear resistance of soil.

CHAPTER (4)

ANALYSIS AND NUMERICAL RESULTS

4.1. Introduction

Finite element analyses are performed to evaluate the effect of the existence of a berm on the stability of cantilever walls. The effect of the berm depends on its geometry as shown in Figure (4.1). Referring to this figure, the geometry of the berm is defined by:

Hb = Height of berm

Bt = Top width of berm

1:m = Slope of berm (VL. To HL.)

Noting that:

Hw = Free height of the wall.

H = Total height of the wall.

d = Driven depth of the wall.

As can be seen in Figure (4.1)

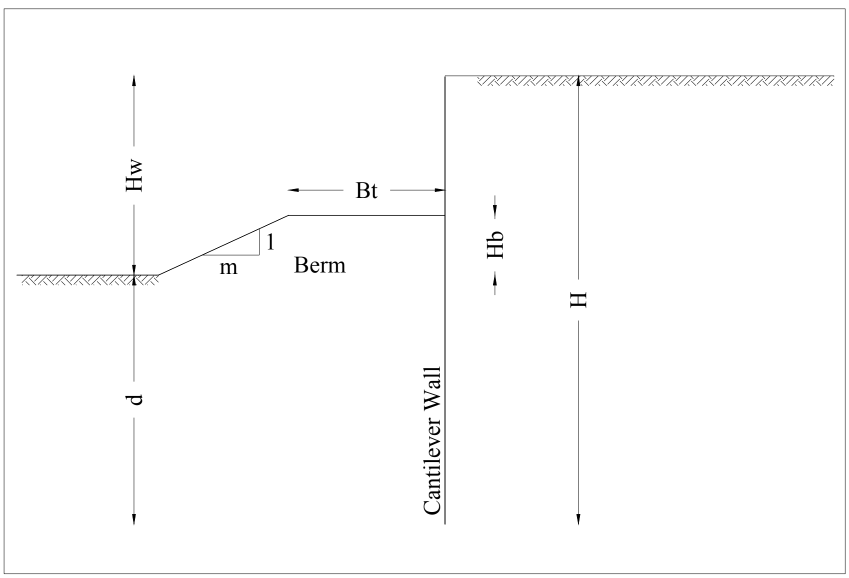


Figure (4.1): Geometry of Bermed Cantilever Wall

Parametric studies of the various geometry components of the berm were performed. This was performed for different values of wall height, Hw. Noting that the driven depth, d always assumes a value equal to 1.25 times the free wall height, Hw.

4.2. Properties of the Elements in the Model

The finite element analysis requires the properties of the elements, which are included in the model. The model contains different elements. These elements are soil elements, wall elements and interface elements. The properties of these elements have a considerable effect on the results of analysis.

4.2.1. Properties of Soil Elements

The analysis is performed for cohesionless soils with different shear strengths. The shear strength of soil is indicated by the ultimate angle of shearing resistance,ϕ, and the stress-strain relation of soil by the modulus of elasticity, E. The soil is classified into five groups according to the angle of shearing resistance, ϕ, which is selected to be 28, 30, 32, 34 and 36 degree. The properties of each group are presented in Table (4.1).

Where:

ϕ = Angle of shear friction.
Ψ = Angle of dilatation.
E = Primary loading stiffness of soil.
γ_d = Dry unit weight of soil.
E_{ur} = Unloading reloading stiffness of soil.
m = Power in stiffness law
R_f = Failure ratio
ν_{ur} = Unloading reloading Poisson's ratio of soil.
Ko = Coefficient of at rest earth pressure.

Group No.	φ degree	E (kN/m^2)	γ_d (kN/m^3)	E_{ur} (kN/m^2)	K_o	.m	R_f	ν_{ur}
1	28	20000	17	60000	0.531	0.5	0.90	0.20
2	30	25000	17	75000	0.50	0.5	0.90	0.20
3	32	30000	17	90000	0.470	0.50	0.90	0.20
4	34	35000	17	105000	0.44	0.50	0.90	0.20
5	36	40000	17	120000	0.412	0.50	0.90	0.20

Table (4.1): Properties of Soil Groups

4.2.2. Properties of Beam Elements (Walls)

The properties of the wall are selected to simulate the more common structures used in practical projects. The properties are selected for two different concrete diaphragm walls with 0.60-m and 0.80-m thick or any wall that has the same stiffness flexural rigidity and axial stiffness rigidity. The wall is considered to be elastic in the present analysis. As stated before the wall is modeled using beam elements. The properties of the beam elements used in the analysis are summarized in Table (4.2).

No.	Property	Group (1)	Group (2)	Unit
1	Flexural rigidity per meter	1.26E7	1.68E7	kN/m
2	Axial stiffness per meter	3.78E5	8.96E5	$kN.m^2/m$
3	Unit weight per meter	15.00	20.00	kN/m
4	Poisson's Ratio	0.25	0.25	-
5	Equivalent wall thickness	0.60	0.80	.m

Table (4.2): Properties of Wall Groups

4.2.3. Properties of Interface Elements

Interface elements are assigned around the beam elements (wall) to model the soil-structure interaction. The behavior of interface elements is described by Coulomb's criterion. The interface properties are calculated from soil properties around it using strength reduction factor, Ri by applying equation (4.1). The stress reduction factor, R_i is taken equal to 0.67, which is the most common value for friction between the sand and concrete.

$$\tan(\delta) = R_i \tan(\phi) \qquad (4\text{-}1)$$

Where:

δ = Angle of friction between soil and the wall.

Ri = Shear strength reduction factor.

ϕ = Angle of internal friction.

4.3. Aspects of Finite Element Model

The configuration of the finite element model has a considerable effect on the analysis. The main aspects of the model are its dimensions, shape of elements and distribution of the elements throughout the modeled domain. The initial stresses that include the initial effective stress and initial pore water pressure affect the results of analysis as well.

4.3.1. Dimensions of Finite Element Model

The mesh dimensions are selected large enough to avoid the effect of boundary conditions on the results of the analysis. These dimensions of the domain are selected according the rules proposed by Fethi Aziz, (1999). Trials are made on the dimensions by increasing the dimensions and recording the results for every increase until the increase of the domain has no effect on the results. The selected dimensions for every wall height are shown in Figures (4.2) to (4.4).

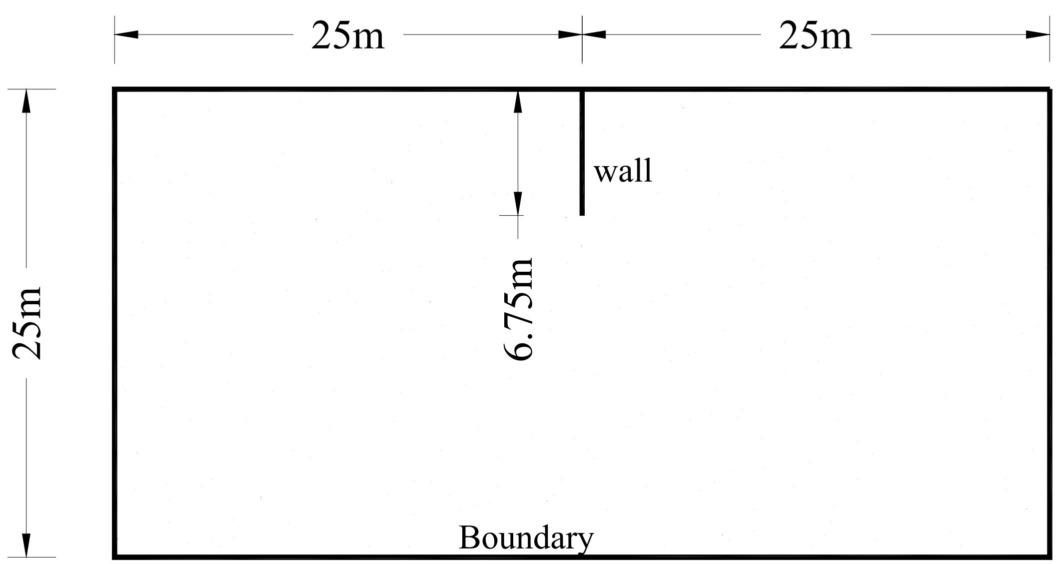


Figure (4.2): Dimensions of the Finite Element Mesh For Wall with 3.0m Free Height

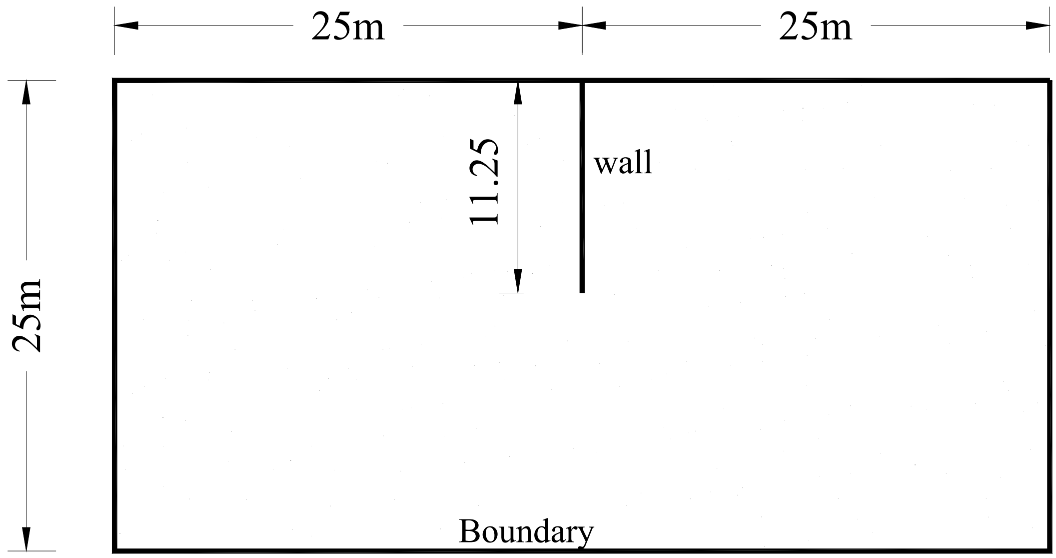


Figure (4.3): Dimension of the Finite Element Mesh
For Wall with 5.0m Free Height

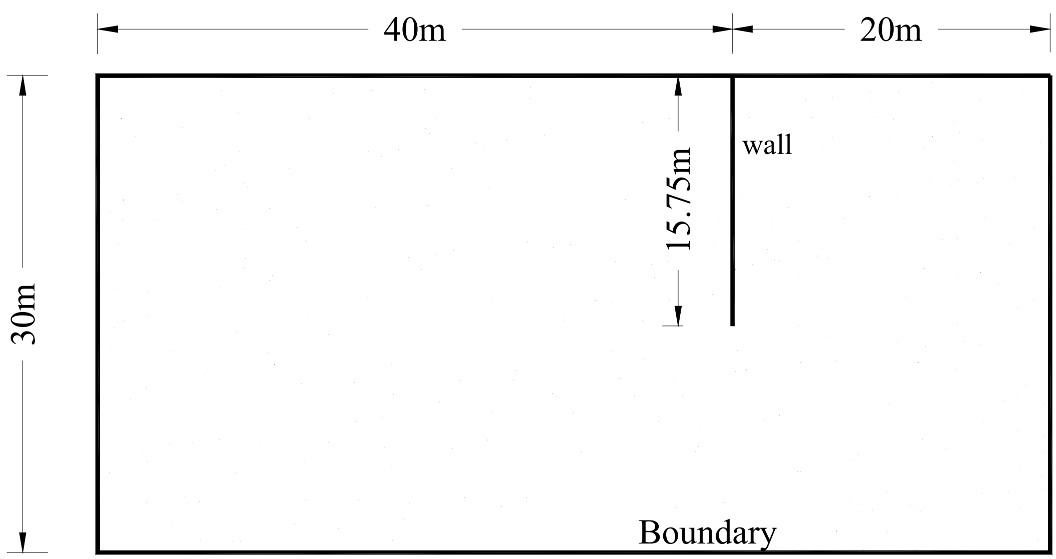


Figure (4.4): Dimension of the Finite Element Mesh
For Wall with 7.0m Free Height

4.3.2. Distribution of Elements in the Model

The domain is divided into finite elements. The 15-noded triangular element is used in the mesh to model the soil. The top node of the wall is selected to generate the load-displacement curve of the analysis. This node is the most suitable node to express the deformation during of the wall. These elements contain 12 stress points where the stresses are calculated from Gausssian integration.

The number of finite elements in the mesh has an important effect on the results of the analysis. Thus, the degree of coarseness of the mesh must be properly selected. The selection of the degree of coarseness is made after several trials of analysis using different degree of coarseness. The medium degree of coarseness was found to be the most suitable. Any refinement of the mesh over the medium degree does not affect the results of analysis. Also, local refinement of mesh around the wall is made to give more accurate results. The number of elements in the mesh according to the selected degree of coarseness is (454) for the wall with 3-m free height, (530) for the wall with 5-m free height and (662) for the wall with 7-m free height. The distribution of elements in the different meshes is presented in Figures (4.5) to (4.7) for different wall heights.

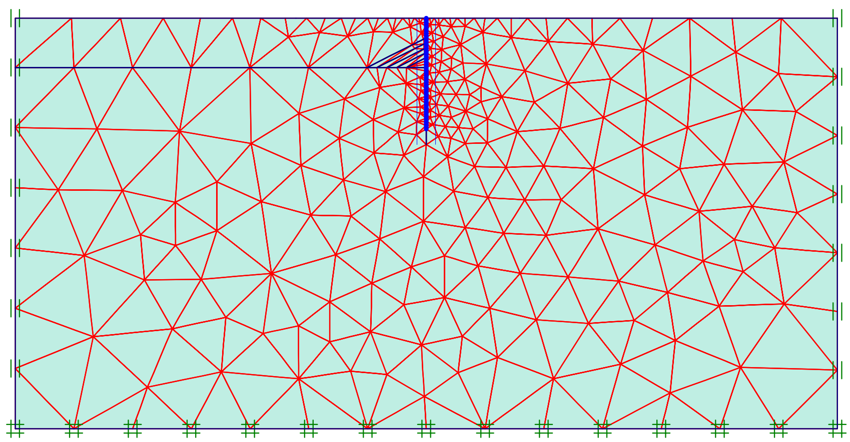


Figure (4.5): The Finite

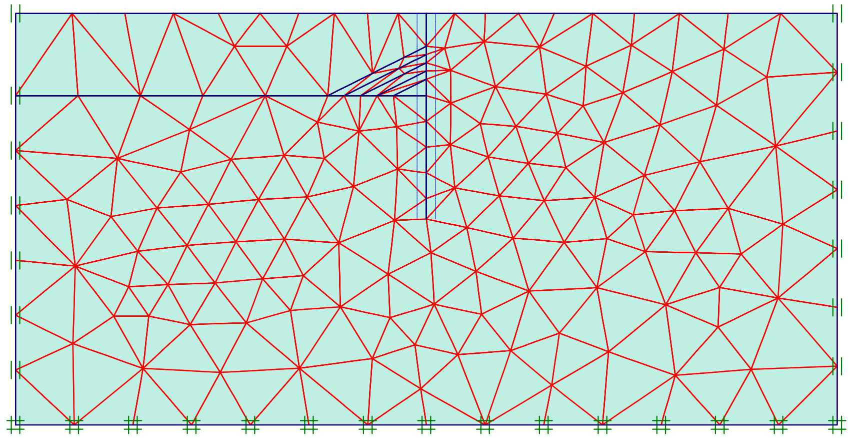


Figure (4.6): The Finite Element Mesh for 5.0m Free Height Wall

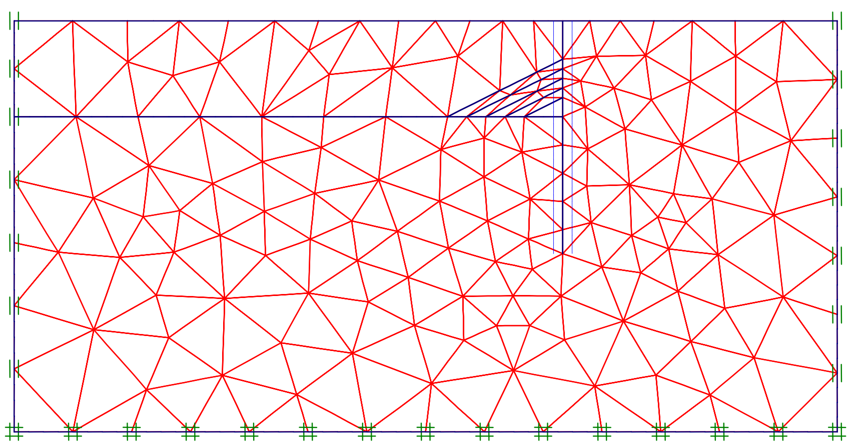


Figure (4.7): The Finite Element Mesh for 7.0m Free Height Wall

4.4. Results of Finite Element Analysis

Analyses have been performed for soil Groups (1) to (5) being retained by both wall Groups (1) and (2). Soil and wall properties are shown in Tables (4.1) to (4.2), respectively. This results in a set of ten solutions. It is to be noted that in the main body of discussions of two solutions for both wall groups retaining soil group No. (1) only are presented. The remaining eight solutions are shown in the Appendices (2) to (5). This is done to avoid repetition. For each soil group, the free height of the wall is varied to model practical wall dimensions. The free wall height in the analyses was taken equal to 3.0, 5.0, and 7.0m. The numerical results of the analysis are presented below for different soil groups, wall groups and berm geometry.

4.4.1. Effect of Varying Driven Depth of the Wall

In this analysis the total wall height, H, refer to Figure (4.1) is kept constant while the driven depth , d, is varied. The driven depth of the wall is taken equal to 1.25 times the free height in the initial analysis. In Each subsequent analysis, the driven depth is increased by 0.20m while the total height is remaining constant as shown in Figure (4.8). Each time, the maximum bending moment and the horizontal movement of the top point are calculated. The results of analyses for the different walls having total heights, H, equals 6.75, 11.25, and 15.75m height are presented in Tables (4.3) to (4.5) for soil group No. (1).

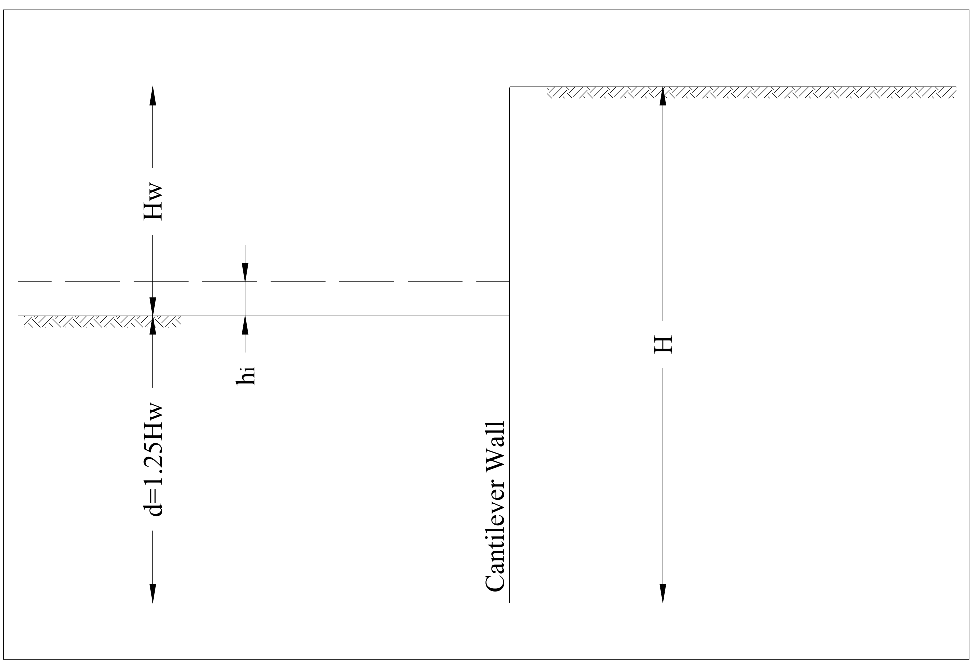


Figure (4.8): Increase in Driven Depth for Constant Wall Height

Where:

Hw: Free height of the wall is considered (3, 5, 7) m

d : Driven depth of the wall is considered 1.25 Hw

H : Total Height of the wall (constant)

hi : Increase in driven depth,(Decrease in free height)

4.4.1.1. Moment and Deflection for 3.0m Initial Free Height Wall

Free Height (m)	Driven Depth (m)	Increase in Driven depth .hi, (m)	Wall Group(1)		Wall Group(2)	
			Moment (kN.m/m')	Deflection (mm)	Moment (kN.m/m')	Deflection (mm)
3.00	3.75	0.00	53.82	21.10	61.02	30.36
2.80	3.95	0.20	48.37	14.85	56.12	21.65
2.60	4.15	0.40	42.94	10.71	49.87	15.32
2.40	4.35	0.60	38.17	7.54	46.69	11.73
2.20	4.55	0.80	33.08	5.43	41.43	8.41
2.00	4.75	1.00	29.59	4.08	36.94	6.16
1.80	4.95	1.20	24.61	2.78	33.02	4.79
1.60	5.15	1.40	19.55	1.60	28.52	3.53
1.40	5.35	1.60	16.44	0.95	24.33	2.52

Table (4.3): Bending Moment and Deflection
3.0m Initial Free Height Wall

4.4.1.2. Moment and Deflection for 5.0m Initial Free Height Wall

Free Height (m)	Driven Depth (m)	Increase in Driven depth .hi, (m)	Wall Group(1)		Wall Group(2)	
			Moment (kN.m/m')	Deflection (mm)	Moment (kN.m/m')	Deflection (mm)
5.00	6.25	0.00	223.59	42.31	252.10	48.30
4.80	6.45	0.20	205.45	36.06	226.39	36.88
4.60	6.65	0.40	188.68	29.97	206.91	29.63
4.40	6.85	0.60	174.23	25.60	191.89	24.52
4.20	7.05	0.80	153.05	20.53	175.12	20.37
4.00	7.25	1.00	139.14	17.35	158.71	16.70
3.80	7.45	1.20	12.3.51	14.27	146.53	13.94
3.60	7.65	1.40	106.97	11.51	129.30	11.41
3.40	7.85	1.60	90.48	9.08	118.02	9.64
3.20	8.05	1.80	80.41	7.63	100.18	7.32
3.00	8.25	2.00	74.32	6.68	88.38	5.86
2.80	8.45	2.20	60.49	5.05	78.46	4.76
2.60	8.65	2.40	50.25	3.94	69.11	3.86

Table (4.4): Bending Moment and Deflection
5.0m Initial Free Height Wall

4.4.1.3. Moment and Deflection for 7.0m Initial Free Height Wall

Free Height (m)	Driven Depth (m)	Increase in Driven depth .hi, (m)	Wall Group(1)		Wall Group(2)	
			Moment (kN.m/m')	Deflection (mm)	Moment (kN.m/m')	Deflection (mm)
7.00	8.75	0.00	584.43	115.10	621.70	84.31
6.80	8.95	0.20	547.26	102.04	576.81	72.71
6.60	9.15	0.40	505.20	90.03	542.58	63.88
6.40	9.35	0.60	455.18	76.48	499.33	55.37
6.20	9.55	0.80	421.22	68.26	466.72	48.88
6.00	9.75	1.00	384.08	59.38	428.02	42.41
5.80	9.95	1.20	355.70	53.11	397.39	37.81
5.60	10.15	1.40	322.19	46.01	363.94	32.55
5.40	10.35	1.60	291.04	40.21	337.94	29.01
5.20	10.55	1.80	267.20	35.73	309.98	25.37
5.00	10.75	2.00	243.17	31.09	280.28	21.94
4.80	10.95	2.20	214.95	26.63	254.49	19.17
4.60	11.15	2.40	195.25	23.10	223.91	16.10
4.40	11.35	2.60	175.61	19.91	207.79	14.41
4.20	11.55	2.80	154.83	16.81	185.62	12.32

Table (4.5): Bending Moment and Deflection
7.0m Initial Free Height Wall

4.4.2. Curve Fitting for Results

The results of this analysis are fitted to a curve. A polynomial of the third degree versus increase in driven depth, hi provides the best fit for moment. A polynomial of the fourth degree for the movement of the top point of the wall is produced. The curves in Figures (4.8) to (4.10) presented the relationship between the maximum bending moment on the wall versus increasing in the driven depth for the three wall heights. The relationship between the movement and increase in driven depth is presented in Figures (4.11) to (4.13).

Polynomials for walls for soil group No. (1) having a 28degree angle of shearing resistance and wall group No. (1) are as follow:

1. Wall with 3-m Initial Free Height

$$M = -0.64h_i^3 + 3.94h_i^2 - 28.20h_i + 53.79 \qquad (4\text{-}3)$$

$$D = 3.13h_i^4 - 15.82h_i^3 + 32.51h_i^2 - 36.95h_i + 21.10 \qquad (4\text{-}4)$$

2. Wall with 5-m Initial Free Height

$$M = 3.52h_i^3 - 2.20h_i^2 - 86.56h_i + 223.59 \quad (4\text{-}5)$$

$$D = -0.41h_i^4 + 0.67h_i^3 + 7.97h_i^2 - 33.38h_i + 42.31 \quad (4\text{-}6)$$

3. Wall with 7-m Initial Free Height

$$M = -21.20h_i^3 + 34.29h_i^2 - 233.93h_i + 588.31 \quad (4\text{-}7)$$

$$D = -0.20h_i^4 - 3.73h_i^3 + 23.24h_i^2 - 75.49h_i + 115.61 \quad (4\text{-}8)$$

Polynomials for different walls for soil group No. (1) having a 28degree angle of shearing resistance and wall group No. (2) are as follow:

1. Wall with 3-m Initial Free Height

$$M = -1.44h_i^3 + 5.31h_i^2 - 27.81h_i + 61.08 \quad (4\text{-}9)$$

$$D = 4.14h_i^4 - 21.23h_i^3 + 44.88h_i^2 - 51.79h_i + 30.35 \quad (4\text{-}10)$$

2. Wall with 5-m Initial Free Height

$$M = -1.85h_i^3 + 16.93h_i^2 - 105.81h_i + 249.35 \quad (4\text{-}11)$$

$$D = 3.16h_i^4 - 19.24h_i^3 + 45.75h_i^2 - 60.89h_i + 47.97 \quad (4\text{-}12)$$

3. Wall with 7-m Initial Free Height

$$M = -0.95h_i^3 + 22.81h_i^2 - 212.25h_i + 620.77 \quad (4\text{-}13)$$

$$D = 0.81h_i^4 - 6.66h_i^3 + 24.74h_i^2 - 60.41h_i + 84.19 \quad (4\text{-}14)$$

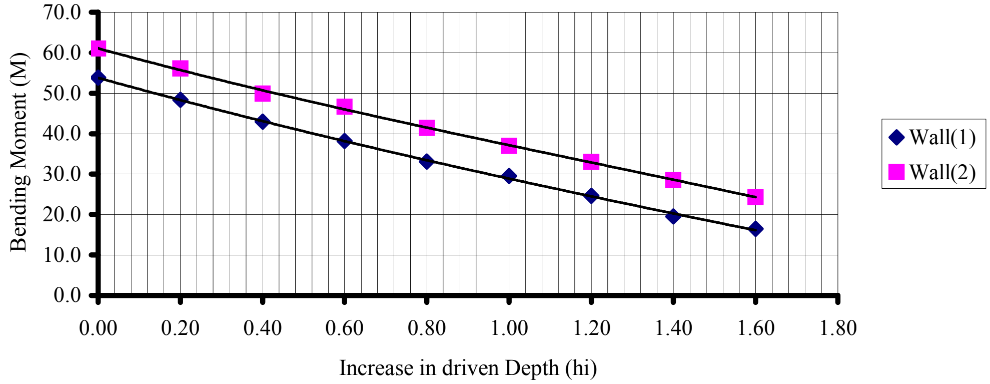


Figure (4.8): Maximum Moment versus Increase in Driven Depth (Hw=3.0m & φ =28°)

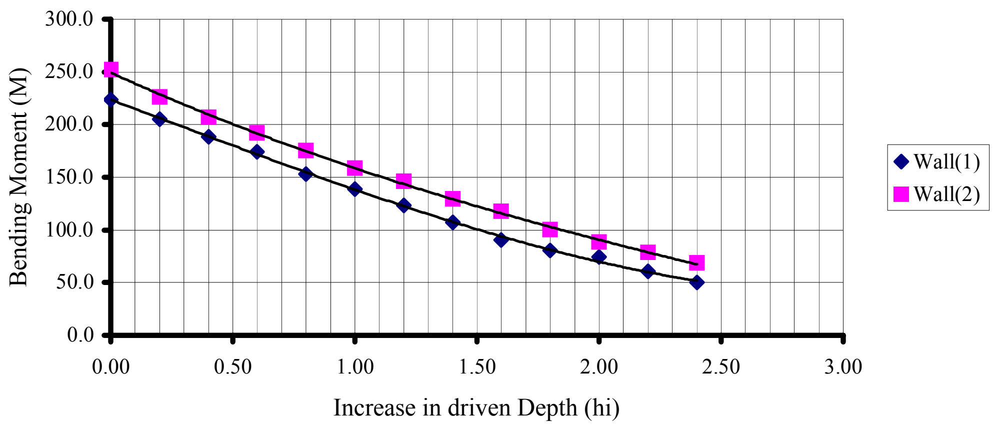


Figure (4.9): Maximum Moment versus Increase in Driven Depth (Hw=5.0m & φ =28°)

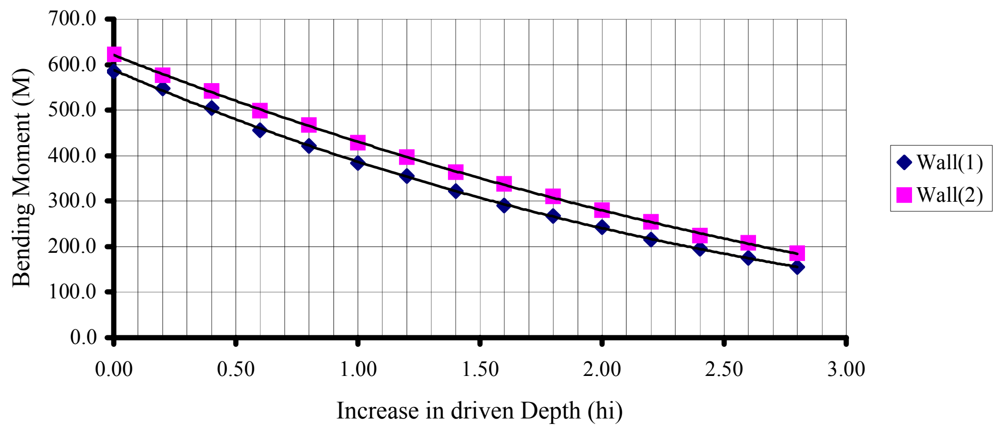


Figure (4.10): Maximum Moment versus Increase in Driven Depth (Hw=7.0m & φ =28°)

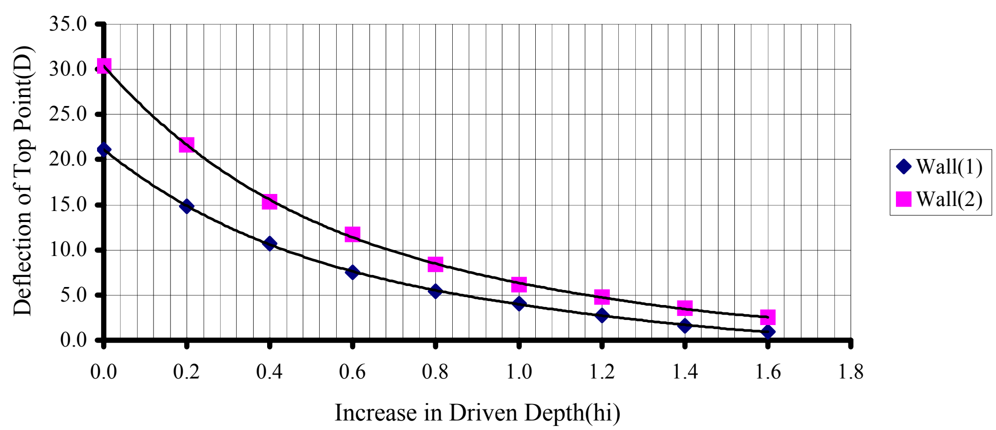


Figure (4.11): Deflection of the Wall versus Increase of Driven Depth (Hw=3.0m & φ =28°)

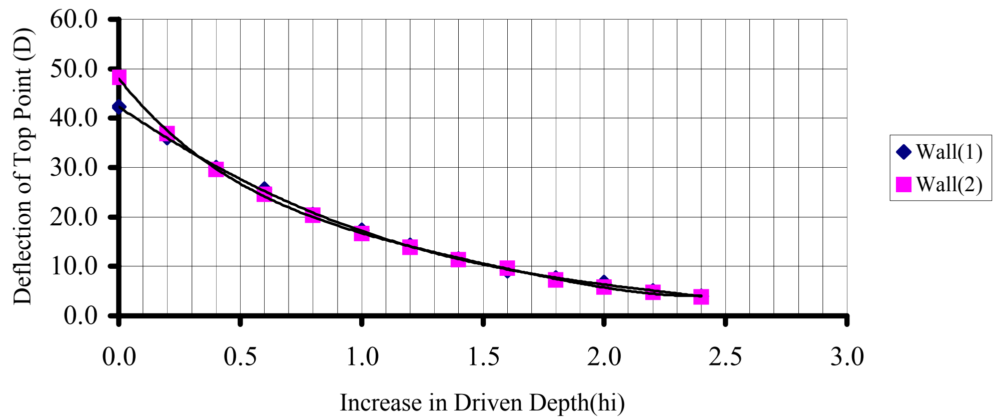
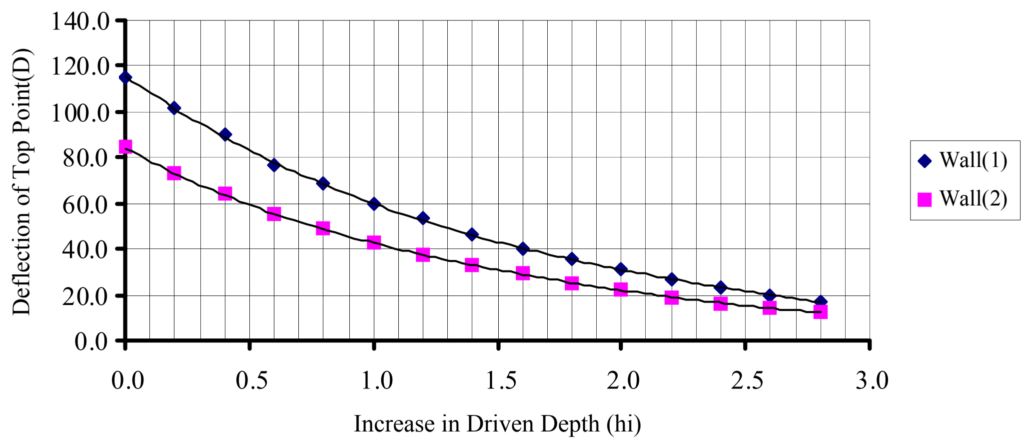


Figure (4.12): Deflection of the Wall versus Increase of Driven Depth (Hw=5.0m & φ =28°)



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gure (4.13): Deflection of the Wall versus Increase of Driven Depth (Hw=7.0m & φ =28°)

4.4.3. Results for Wall with Stabilizing Berm

Effect of berm on the stability of the wall depends on the dimensions and the shape of the berm. The berm can be specified by three parameters. These parameters are the height of berm, H_b, top width of the berm, Bt and slope of berm, horizontal to vertical, (1:m), as in Figure (4.1).

4.4.3.1. Results for Wall with Zero Top Berm Width

The first set of analyses is performed with top berm width taken equal to zero, Figure (4.15). Berm height is taken as a ratio of the free height of the wall. The selected ratios for analysis are 0.2, 0.3, 0.4, 0.50 and 0.60. For each berm height, the slopes of the berm are considered 1:2, 1:3 and 1:4. These slopes are the most common slopes in practice. The bending moment and movement at the top of the wall are calculated for each case. The results of analysis are summarized in Tables (4.6) to (4.8).

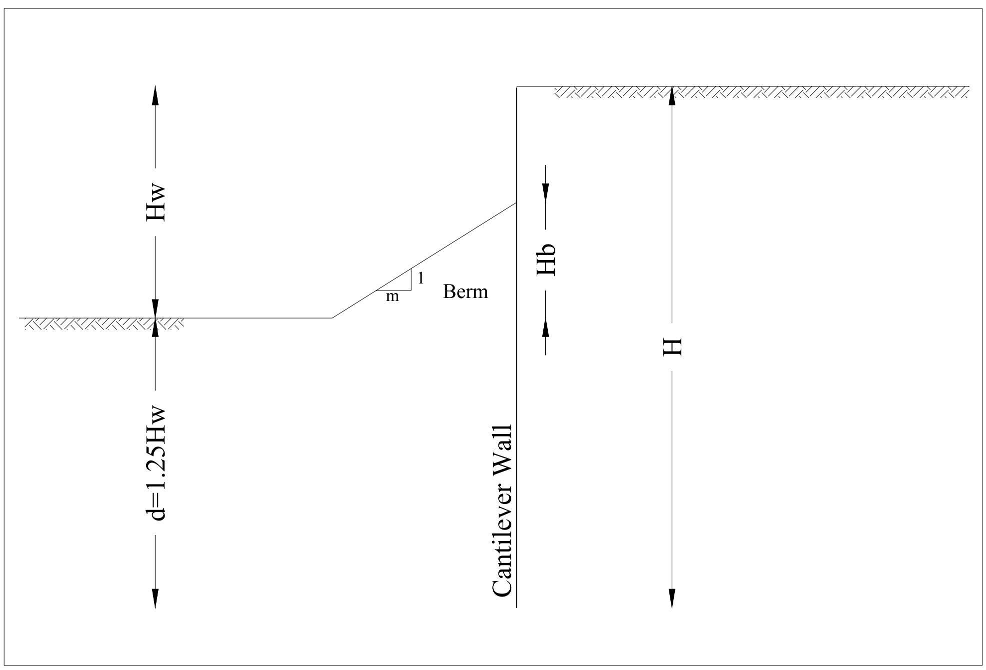


Figure (4.14): Berm with Zero Top Width

Where:

Hw: Free height of the wall is considered (3, 5, 7) m

d : Driven depth of the wall is considered 1.25 Hw

H : The total length of the wall

m : The slope of berm is considered (2, 3, 4)

H_b : The height of berm is considered (0.2, 0.3, 0.4, 0.5, 0.6) Hw

4.4.3.1.1. Moment and Deflection for 3.0m Free Height Wall

Berm Height (m)	Berm Slope VL. To HL.	Wall group No. (1)		Wall group No. (2)	
		Moment (kN.m/m')	Deflection (mm)	Moment (kN.m/m')	Deflection (mm)
0.60	1 : 2	47.42	17.17	55.09	24.85
0.60	1 : 3	44.80	15.61	51.76	21.81
0.60	1 : 4	41.94	13.26	48.71	19.02
0.90	1 : 2	41.04	13.35	48.54	19.42
0.90	1 : 3	37.95	11.30	44.05	16.16
0.90	1 : 4	35.65	9.40	41.33	13.65
1.20	1 : 2	35.58	10.14	41.96	15.01
1.20	1 : 3	31.22	7.79	37.26	11.03
1.20	1 : 4	28.63	5.69	35.54	8.95
1.50	1 : 2	29.21	7.07	36.47	11.38
1.50	1 : 3	23.88	4.30	31.11	7.38
1.50	1 : 4	22.41	2.90	30.24	5.51
1.80	1 : 2	24.02	4.46	31.50	7.74
1.80	1 : 3	18.50	2.14	25.66	4.35
1.80	1 : 4	17.02	0.725	24.59	2.76

Table (4.6): Moment and Deflection for Wall with Zero Top Berm Width
3.0m Free Height Wall

4.4.3.1.2. Moment and Deflection for 5.0m Free Height Wall

Berm Height (m)	Berm Slope VL. To HL.	Wall group No.(1)		Wall group No.(2)	
		Moment (kN.m/m')	Deflection (mm)	Moment (kN.m/m')	Deflection (mm)
1.00	1 : 2	195.31	36.22	207.83	35.56
1.00	1 : 3	178.90	32.42	193.87	32.27
1.00	1 : 4	168.79	29.24	181.66	27.96
1.20	1 : 2	159.500	27.65	182.34	29.00
1.20	1 : 3	138.96	22.98	152.31	21.92
1.20	1 : 4	123.44	18.61	147.76	20.25
1.50	1 : 2	128.95	20.97	145.44	20.94
1.50	1 : 3	97.63	14.15	123.73	16.22
1.50	1 : 4	84.90	10.53	113.40	12.86
1.50	1 : 2	90.34	13.16	121.40	16.18
1.50	1 : 3	66.78	8.32	89.90	9.47
1.50	1 : 4	60.46	6.08	77.86	6.53
1.80	1 : 2	64.64	8.60	89.90	10.43
1.80	1 : 3	43.10	4.11	60.11	4.82
1.80	1 : 4	38.47	2.51	54.87	3.33

Table (4.7): Moment and Deflection for Wall with Zero Top Berm Width
5.0 m Free Height Wall

3.4.3.1.3. Moment and Deflection for 7.0m Free Height Wall

Berm height (m)	Berm slope VL. To HL.	Wall group No.(1)		Wall group No.(2)	
		Moment (kN.m/m')	Deflection (mm)	Moment (kN.m/m')	Deflection (mm)
1.40	1 : 2	482.07	94.74	517.27	72.83
1.40	1 : 3	435.86	83.52	483.32	66.20
1.40	1 : 4	407.60	73.41	471.97	58.62
2.10	1 : 2	393.67	74.64	440.44	58.04
2.10	1 : 3	314.68	56.16	376.87	47.20
2.10	1 : 4	277.31	46.11	327.28	35.76
2.80	1 : 2	294.18	52.74	352.50	43.66
2.80	1 : 3	212.38	35.13	252.68	27.80
2.80	1 : 4	198.47	29.52	224.21	21.21
3.50	1 : 2	197.81	33.83	263.40	30.42
3.50	1 : 3	136.96	20.24	182.17	17.95
3.50	1 : 4	120.25	14.64	146.74	11.26
4.20	1 : 2	132.98	21.59	165.78	17.12
4.20	1 : 3	82.44	9.95	105.87	8.40
4.20	1 : 4	74.09	6.54	93.72	5.41

Table (4.8): Moment and Deflection for Wall with Zero Top Berm Width
7.0m Free Height Wall

4.4.3.2. Results for Different Top Widths of Berm for Wall Group No. (1)

The top width of berm (Bt) has a considerable effect on the stability of the wall. Increasing the top width leads to a decrease in the bending moment and deflection of the wall. Different top widths are selected to perform the analysis. Refering to Figure (4.16), the top width is taken to be 1.0, 1.50 and 3.0m. The top width is considered to be infinite when the dredge level is increased to the height of berm. The results of bending moment and deflection for soil group No. (1) with different top berm widths are presented in Tables (4.9) to (4.11).

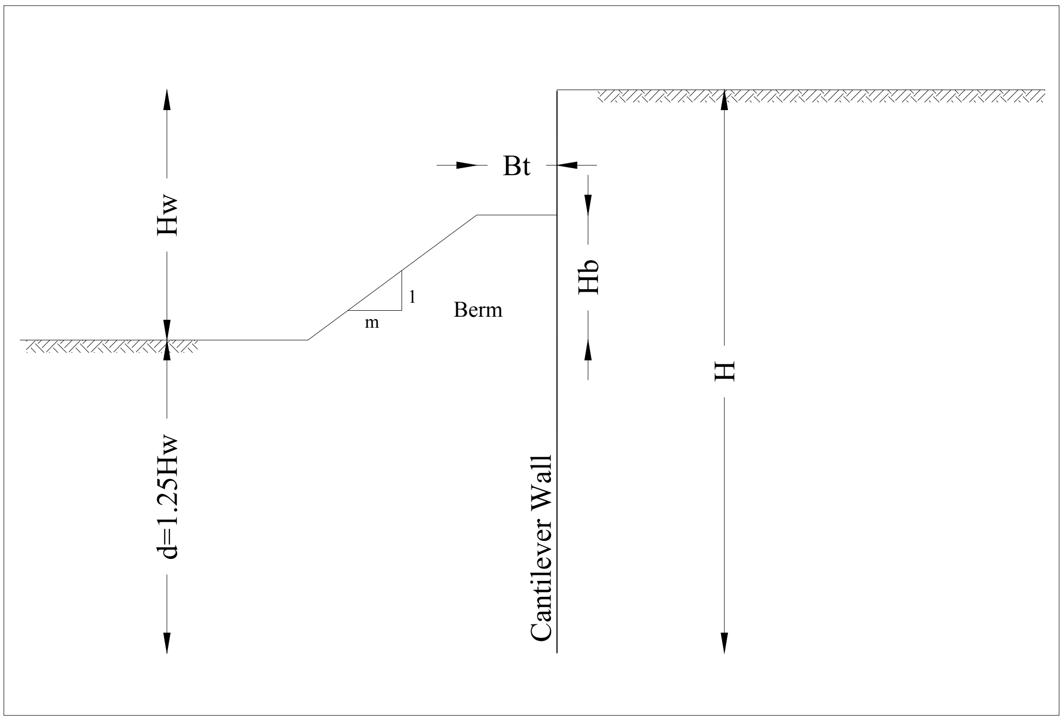


Figure (4.15): Berm with Variable Top Width

Where:

Hw: Free height of the wall is considered (3, 5, 7) m.

d : Driven depth of the wall is considered 1.25 Hw.

H : Total Height of the wall.

m : Slope of berm is considered (2, 3, 4).

Hb: Height of berm is considered (0.2, 0.3, 0.4, 0.5, 0.6) Hw.

Bt : Top width of berm is considered (1.00, 1.50, 3.00) m.

4.4.3.2.1. Moment and Deflection for 3.0m Free Height Wall

Berm height (m)	Berm slope VL. To HL.	Moment (kN.m/m')			Deflection (mm)		
		Bt=1.0	**Bt=1.5**	**Bt=3.0**	**Bt=1.0**	**Bt=1.5**	**Bt=3.0**
0.60	1 : 2	40.32	37.80	36.79	13.01	11.28	8.240
0.60	1 : 3	38.96	36.66	36.65	11.86	9.75	7.580
0.60	1 : 4	37.32	36.77	37.22	10.33	9.18	7.790
0.90	1 : 2	33.14	30.91	30.13	8.85	7.26	4.720
0.90	1 : 3	31.39	31.26	30.74	7.42	6.75	4.620
0.90	1 : 4	30.65	30.31	30.70	6.10	5.65	4.460
1.20	1 : 2	26.79	24.51	24.17	5.85	4.60	2.530
1.20	1 : 3	25.04	24.04	24.35	4.27	3.44	2.230
1.20	1 : 4	24.79	24.20	24.97	3.38	2.78	2.070
1.50	1 : 2	21.07	19.18	18.59	3.59	2.43	0.765
1.50	1 : 3	18.94	18.43	19.51	1.90	1.35	0.832
1.50	1 : 4	19.24	19.28	19.74	1.34	1.06	0.413
1.80	1 : 2	16.42	14.23	14.52	1.59	0.71	0.00
1.80	1 : 3	14.41	13.98	15.60	0.16	0.00	0.00
1.80	1 : 4	14.79	14.83	15.01	0.20	0.00	0.00

Table (4.9): Moment and Deflection for Wall with Different Top Widths of Berm 3.0m Free Height Wall

4.4.3.2.2. Moment and deflection for wall 5.0m Free Height Wall

Berm height (m)	Berm slope VL. To HL.	Moment (kN.m/m')			Deflection (mm)		
		Bt=1.0	**Bt=1.5**	**Bt=3.0**	**Bt=1.0**	**Bt=1.5**	**Bt=3.0**
1.00	1 : 2	178.7	164.3	147.6	32.61	28.87	23.80
1.00	1 : 3	163.9	156.3	136.9	28.84	26.81	20.73
1.00	1 : 4	153.6	152.3	136.5	25.94	24.98	19.99
1.50	1 : 2	138.7	125.7	98.28	23.32	20.40	13.45
1.50	1 : 3	124.4	106.2	96.10	19.68	15.48	11.78
1.50	1 : 4	107.4	102.0	95.49	14.98	13.51	11.02
2.00	1 : 2	104.3	83.35	69.59	16.13	11.83	8.380
2.00	1 : 3	78.30	72.86	67.48	10.09	8.80	6.77
2.00	1 : 4	73.43	71.43	69.30	8.13	7.63	6.48
2.50	1 : 2	64.88	56.87	45.32	8.59	7.09	4.44
2.50	1 : 3	52.70	49.35	46.04	5.78	4.86	3.28
2.50	1 : 4	50.13	47.46	46.27	4.23	3.63	2.82
3.00	1 : 2	46.18	37.39	29.09	5.50	4.13	1.82
3.00	1 : 3	33.56	30.88	31.08	2.40	1.74	0.91
3.00	1 : 4	32.41	31.22	32.28	1.63	1.25	0.86

Table (4.10):Moment and Deflection for Wall with Different Top Widths of Berm 5.0m Free Height Wall

4.4.3.2.3. Moment and Deflection for 7.0m Free Height Wall

Berm height (m)	Berm slope VL. To HL.	Moment (kN.m/m')			Deflection (mm)		
		Bt=1.0	**Bt=1.5**	**Bt=3.0**	**Bt=1.0**	**Bt=1.5**	**Bt=3.0**
1.40	1 : 2	440.8	415.8	363.4	84.64	80.16	66.53
1.40	1 : 3	401.6	387.8	351.1	76.14	72.50	62.68
1.40	1 : 4	384.2	367.2	340.3	68.77	64.47	56.92
2.10	1 : 2	339.4	309.7	268.8	62.62	55.98	46.33
2.10	1 : 3	295.3	279.5	227.2	51.95	48.40	35.60
2.10	1 : 4	254.2	262.4	233.0	40.96	41.92	34.09
2.80	1 : 2	255.6	232.4	177.2	44.99	40.14	28.52
2.80	1 : 3	201.0	183.0	161.6	32.53	28.50	22.38
2.80	1 : 4	178.7	170.7	158.9	25.43	23.37	19.64
3.50	1 : 2	180.5	152.6	98.27	29.88	24.97	14.01
3.50	1 : 3	111.6	102.2	91.16	15.08	13.06	9.68
3.50	1 : 4	103.4	100.7	92.90	11.45	10.82	8.34
4.20	1 : 2	102.8	76.2	53.83	15.87	11.21	6.41
4.20	1 : 3	64.48	60.9	56.68	6.25	5.61	3.44
4.20	1 : 4	63.09	62.8	59.99	4.62	4.38	3.20

Table (4.11):Moment and Deflection for Wall with Different Top Widths of Berm 7.0m Free Height Wall

CHAPTER (5)

DISSCUSION OF RESULTS

5.1. Introduction

The results of finite element analysis introduced in the previous Chapter, will be worked and analyzed to get charts for different types of soil groups and walls. Relationships governing retaining wall behavior versus various parameters are presented. The results will be compared to find the relationships between the results. The results of wall with stabilizing berm are sorted according to the top width of the berm. The results are arranged in simple charts, which may be easily used in the design of the wall with stablizing berm. From the charts, moment and deflection factors may be obtained. These factors are used to calculate the moment and deflection of the wall with berm. Also the equivalent height moment and deflection factors may be obtained. These quantities will be defined in a subsequent section.

Results of the analyses are presented in this Chapter for the soil group No. (1), the properties of which are given in Table (4.1). The results of other groups are presented in Appendices (2) to (5).

5.2. Results of Wall with Zero Top Berm Width

It has been found that the ratio of moments for a wall with and without berm when raised to the power (1/3) is nearly equal for all walls provided that the ratio of berm to wall height is constant. This conclusion may be seen in Table (5.1), which compares between these ratios for different wall heights.

Also, for the same applies to deflection ratios, for walls as described previously. However the power in this case is equal to (1/4). This conclusion may be deduced from Table (5.2), which compares between these ratios for different wall heights.

5.2.1. Results of Wall Group No. (1)

The moment and deflection ratios are compared for different wall heights for wall Group No. (1) having 0.60-m thick. The moment ratios are nearly equal as shown in Table (5.1) where the deflection ratios are in Table (5.2). It is clear that the difference between these ratios are increased with the increase in the ratio of berm to wall height. But, this difference is small which may be neglected.

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Mb/M)^{1/3}$	Hw=5.00 $(Mb/M)^{1/3}$	Hw=7.00 $(Mb/M)^{1/3}$
0.20	1 : 2	0.96	0.95	0.94
0.20	1 : 3	0.94	0.92	0.91
0.20	1 : 4	0.92	0.91	0.89
0.30	1 : 2	0.91	0.89	0.88
0.30	1 : 3	0.89	0.85	0.83
0.30	1 : 4	0.87	0.82	0.78
0.40	1 : 2	0.87	0.83	0.80
0.40	1 : 3	0.83	0.80	0.79
0.40	1 : 4	0.81	0.78	0.77
0.50	1 : 2	0.82	0.79	0.78
0.50	1 : 3	0.76	0.73	0.71
0.50	1 : 4	0.75	0.72	0.70
0.60	1 : 2	0.76	0.74	0.71
0.60	1 : 3	0.70	0.68	0.65
0.60	1 : 4	0.68	0.65	0.63

Table (5.1): Comparison between Moment Ratios for Wall Group No. (1)

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Db/D)^{1/4}$	Hw=5.00 $(Db/D)^{1/4}$	Hw=7.00 $(Db/D)^{1/4}$
0.20	1 : 2	0.81	0.85	0.82
0.20	1 : 3	0.76	0.73	0.76
0.20	1 : 4	0.68	0.64	0.68
0.30	1 : 2	0.65	0.65	0.65
0.30	1 : 3	0.54	0.49	0.54
0.30	1 : 4	0.49	0.40	0.45
0.40	1 : 2	0.49	0.46	0.49
0.40	1 : 3	0.33	0.31	0.37
0.40	1 : 4	0.25	0.26	0.27
0.50	1 : 2	0.31	0.29	0.34
0.50	1 : 3	0.19	0.18	0.20
0.50	1 : 4	0.14	0.13	0.14
0.60	1 : 2	0.20	0.19	0.21
0.60	1 : 3	0.10	0.09	0.10
0.60	1 : 4	0.06	0.06	0.06

Table (5.2): Comparison between Deflection Ratios for Wall Group No. (1)

Figure (5.1) shows the bermed wall used in this analysis. Figures (5.2) and (5.3) illustrate the relation between average moment and deflection factor versus the berm to wall height ratio respectively. From these figures, it is clear that the berm has a more significant effect on the deflection than its effect on the moment. When the berm to wall height ratio for a wall is varied from 0.20 to 0.60, the reduction in moment varies from about 15% to 65%, while the reduction in deflection varies from about 20% to 82%. The berm has a more significant effect on the deflection than its effect on the moment. The increase of the berm slope has little effect on the reduction of the moment and deflection of the cantilever wall. Be that as it may, the slopes effect on deflections is more pronounced than on moments. The increase of the slope from 1:2 to 1:4 reduces the moment on the wall by about 20% and the deflection by about 30%. The effect of increasing slope is gradually less pronounced on wall behavior.

The effect of the berm on the moment increases with increasing wall stiffness. The moment reduction due to the berm increases from 40% to 50%, for wall Groups No.(1) and (2) respectively. The effect of wall stiffness on the deflection factor is relatively small as seen from Figures (5.3) and (5.6).

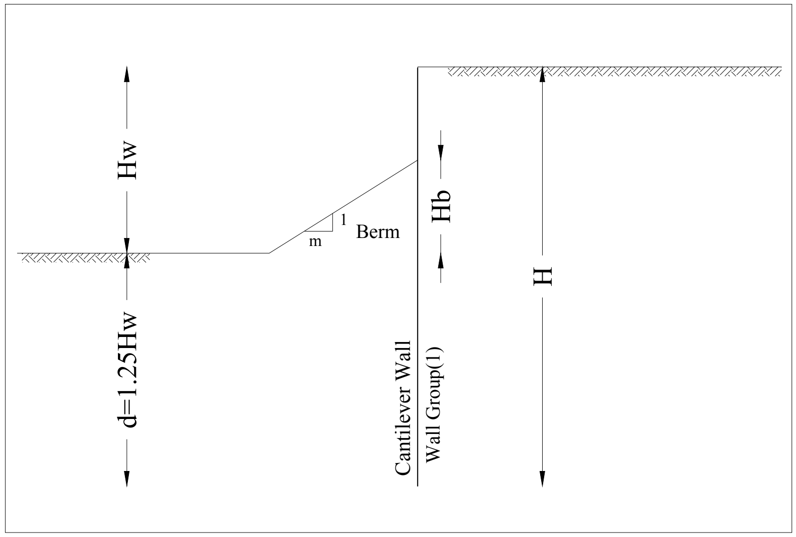


Figure (5.1): Geometry of Bermed Wall with Zero Top Width

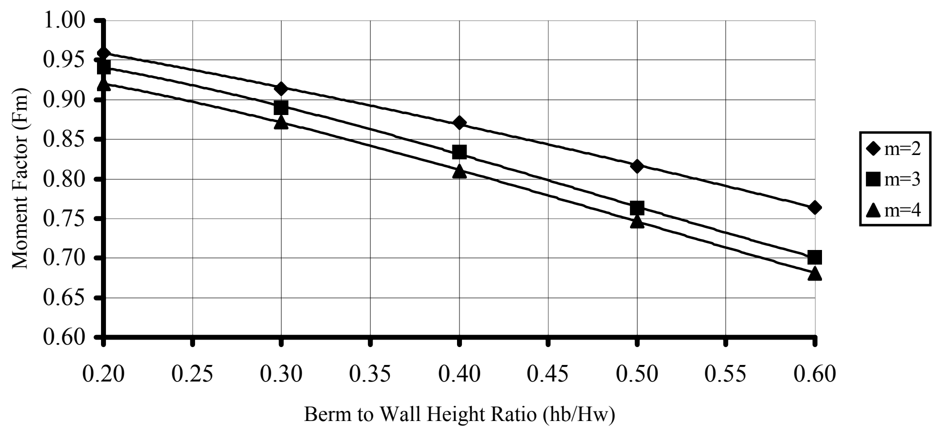


Figure (5.2): Moment Factor versus Berm to Wall Height Ratio
(φ =28° & Wall Group No. (1))

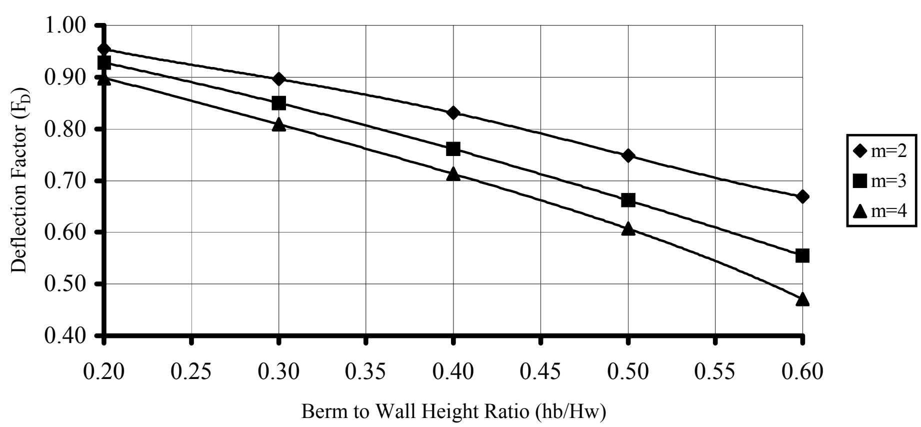


Figure (5.3): Deflection Factor versus Berm to Wall Height Ratio
(φ =28° & Wall Group No. (1))

5.2.2. Results of Wall Group No. (2)

Here, same procedure of analysis is followed as for the 0.60-m wall thick, wall Group No. (1). The final comparison between the ratio of moment and deflection for different wall heights are shown in Tables (5.3) and (5.4). Figures (5.5) and (5.6) present the relationship between moment or deflection factor versus berm to wall height ratio.

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Mb/M)^{1/3}$	Hw=5.00 $(Mb/M)^{1/3}$	Hw=7.00 $(Mb/M)^{1/3}$
0.20	1 : 2	0.42	0.44	0.42
0.20	1 : 3	0.49	0.49	0.46
0.20	1 : 4	0.54	0.52	0.48
0.30	1 : 2	0.55	0.52	0.51
0.30	1 : 3	0.61	0.60	0.57
0.30	1 : 4	0.65	0.61	0.62
0.40	1 : 2	0.64	0.62	0.60
0.40	1 : 3	0.69	0.67	0.68
0.40	1 : 4	0.71	0.69	0.70
0.50	1 : 2	0.70	0.67	0.67
0.50	1 : 3	0.75	0.74	0.74
0.50	1 : 4	0.76	0.76	0.75
0.60	1 : 2	0.75	0.74	0.75
0.60	1 : 3	0.80	0.80	0.80
0.60	1 : 4	0.81	0.81	0.81

Table (5.3): Comparison between Moment Ratios for Wall Group No. (2)

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Db/D)^{1/4}$	Hw=5.00 $(Db/D)^{1/4}$	Hw=7.00 $(Db/D)^{1/4}$
0.20	1 : 2	0.44	0.44	0.42
0.20	1 : 3	0.49	0.49	0.46
0.20	1 : 4	0.52	0.52	0.48
0.30	1 : 2	0.52	0.52	0.51
0.30	1 : 3	0.60	0.60	0.57
0.30	1 : 4	0.61	0.61	0.62
0.40	1 : 2	0.62	0.62	0.60
0.40	1 : 3	0.67	0.67	0.68
0.40	1 : 4	0.69	0.69	0.70
0.50	1 : 2	0.67	0.67	0.67
0.50	1 : 3	0.74	0.74	0.74
0.50	1 : 4	0.76	0.76	0.75
0.60	1 : 2	0.74	0.74	0.75
0.60	1 : 3	0.80	0.80	0.80
0.60	1 : 4	0.81	0.81	0.81

Table (5.4): Comparison between Deflection Ratios for Wall Group No. (2)

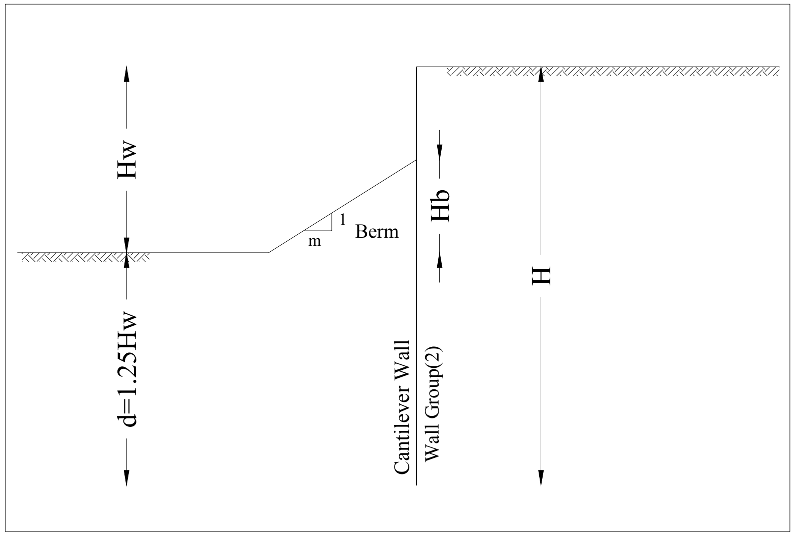


Figure (5.4): Geometry of Bermed Wall with Zero Top Width

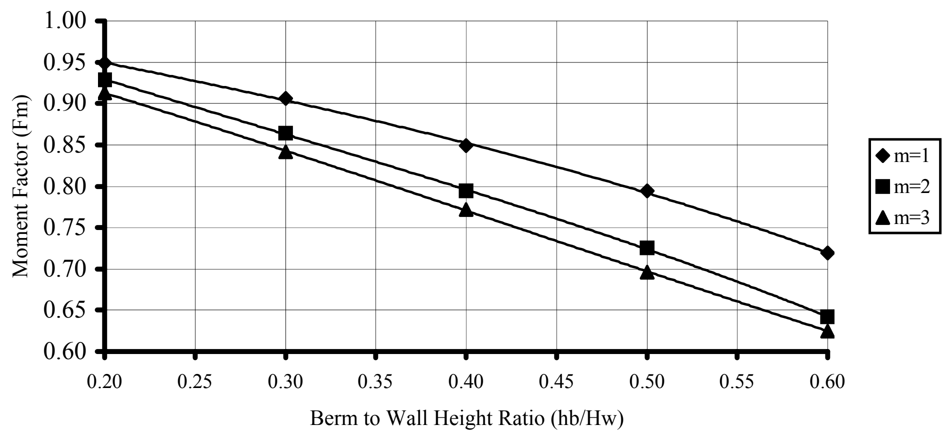


Figure (5.5): Moment Factor versus Berm to Wall Height Ratio
(φ =28° & Wall Group No. (2))

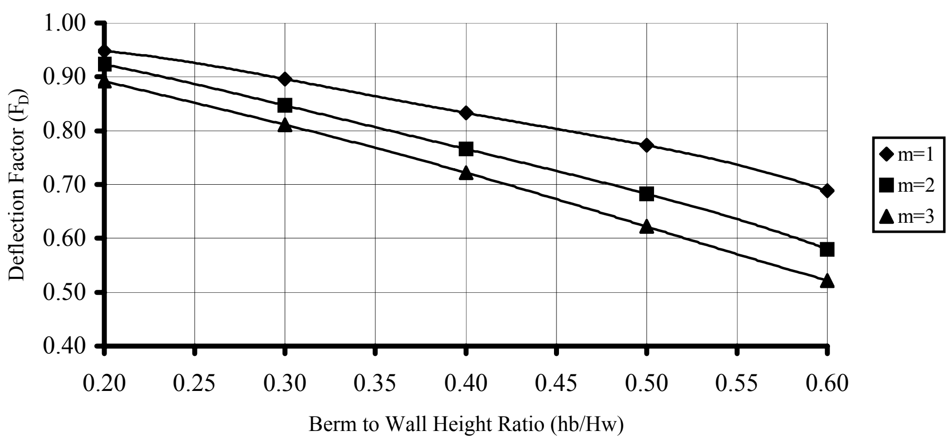


Figure (5.6): Deflection Factor versus Berm to Wall Height Ratio
(φ =28° & Wall Group No. (2))

5.3. Results of Wall with Different Top Berm Widths

The analysis is performed for different soil groups. Comparison is made among the results for three different top berm widths. Comparison of results of bending moment for soil group No. (1) with different top berm widths are presented in Table (5.5) and deflection in Table (5.6). Figures (5.8) and (5.9) show the relationship between moment and deflection factors versus berm to wall height ratio respectively for different berm widths. The slope in these analyses is kept constant at a value equal to1:2.

Berm to wall height Ratio (Hb/Hw)	Slope .m	Bt=0.00 $(Mb/M)^{1/3}$	Bt=1.00 $(Mb/M)^{1/3}$	Bt=1.50 $(Mb/M)^{1/3}$	Bt=3.00 $(Mb/M)^{1/3}$
0.20	1 : 2	0.95	0.92	0.89	0.87
0.20	1 : 3	0.92	0.89	0.88	0.86
0.20	1 : 4	0.91	0.87	0.87	0.86
0.30	1 : 2	0.89	0.84	0.82	0.78
0.30	1 : 3	0.85	0.80	0.80	0.77
0.30	1 : 4	0.82	0.76	0.75	0.74
0.40	1 : 2	0.83	0.77	0.74	0.71
0.40	1 : 3	0.77	0.72	0.71	0.70
0.40	1 : 4	0.74	0.66	0.70	0.70
0.50	1 : 2	0.75	0.67	0.66	0.61
0.50	1 : 3	0.68	0.62	0.60	0.61
0.50	1 : 4	0.66	0.57	0.55	0.62
0.60	1 : 2	0.68	0.58	0.54	0.53
0.60	1 : 3	0.60	0.57	0.55	0.55
0.60	1 : 4	0.58	0.56	0.55	0.55

Table (5.5): Comparison between Moment Ratios
Different Top Berm Widths

Berm to wall height Ratio (Hb/Hw)	Slope .m	Bt=0.00 $(Db/D)^{1/4}$	Bt=1.00 $(Db/D)^{1/4}$	Bt=1.50 $(Db/D)^{1/4}$	Bt=3.00 $(Db/D)^{1/4}$
0.20	1 : 2	0.95	0.92	0.89	0.84
0.20	1 : 3	0.93	0.89	0.87	0.82
0.20	1 : 4	0.90	0.87	0.85	0.81
0.30	1 : 2	0.90	0.84	0.81	0.74
0.30	1 : 3	0.85	0.80	0.78	0.72
0.30	1 : 4	0.81	0.76	0.75	0.71
0.40	1 : 2	0.83	0.77	0.73	0.65
0.40	1 : 3	0.76	0.70	0.67	0.62
0.40	1 : 4	0.71	0.66	0.64	0.61
0.50	1 : 2	0.75	0.67	0.63	0.53
0.50	1 : 3	0.66	0.59	0.55	0.50
0.50	1 : 4	0.61	0.54	0.52	0.47
0.60	1 : 2	0.67	0.58	0.51	0.46
0.60	1 : 3	0.55	0.46	0.42	0.40
0.60	1 : 4	0.47	0.43	0.40	0.39

Table (5.6): Comparison between Deflection Ratios
Different Top Berm Widths

In general, top berm width reduces both the moments and deflections and has a more pronounced effect on deflections. It may be seen that for soil types and wall groups analyzed in this research a top berm with about three meters is equivalent to reducing the dredged depth, Hw, to the height of berm. That is to say berm widths greater than three meters have little effect on wall moment and deflection reduction as seen from Figures (5.8) and (5.9).

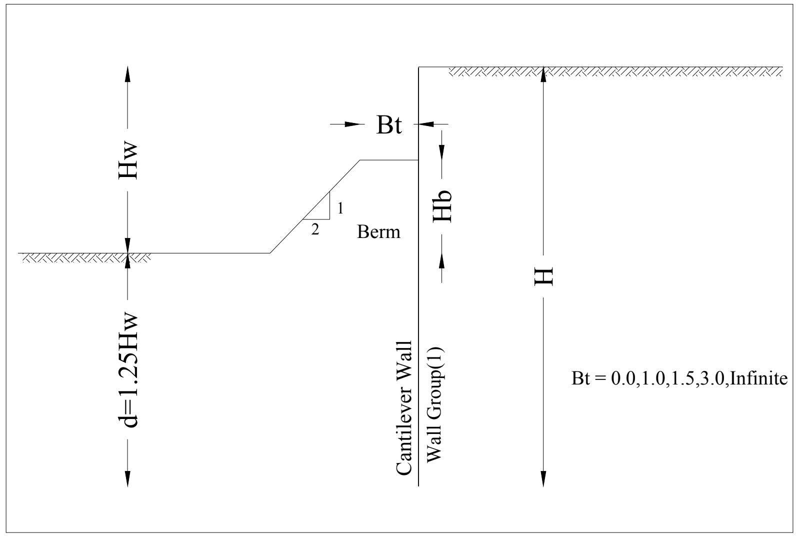


Figure (5.7): Geometry of the Bermed Wall
with Different Top Berm Widths

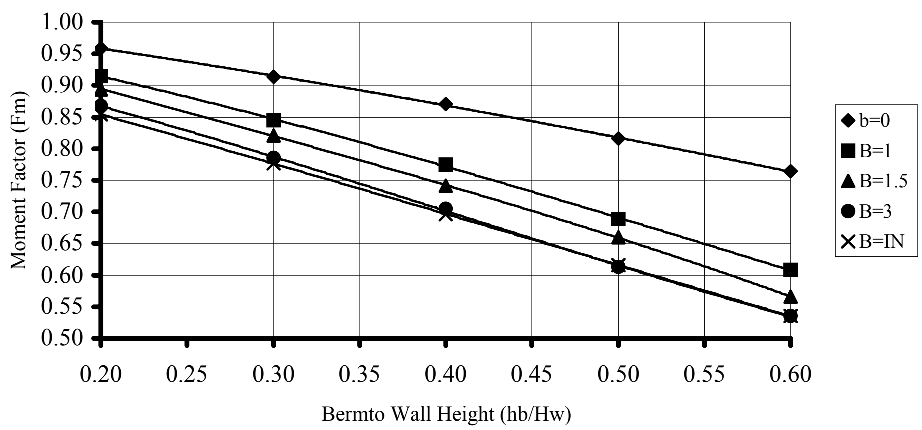


Figure (5.8): Moment Factor versus Berm to Wall Height Ratio
(φ =28° & Wall Group No. (1))

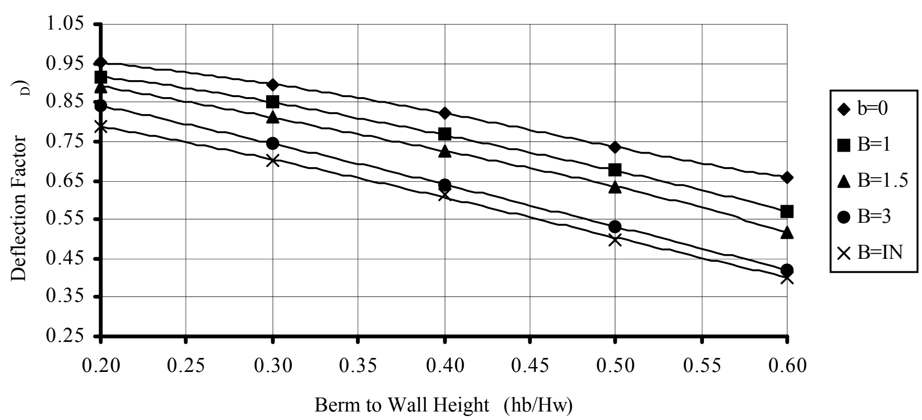


Figure (5.9): Deflection Factor versus Berm to Wall Height Ratio
(φ =28° & Wall Group No. (1))

5.4. Equivalent Moment and Deflection Heights of Wall with Zero Top Berm Width

Equations (4-1), (4-3) and (4-5) are used to deduce the equivalent moment height for the berm. The equivalent moment height, h_{em} is defined as the increase in elevation of soil on the passive side that yields a reduction in moment equal to that which a specific berm produces. This concept may be applied to deflection also. Therefore, we define h_{em} and h_{ed} are the equivalent moment and deflection heights. It has been found that the equivalent moment height is different from the equivalent deflection height. The ratio of the equivalent moment height to the free height of the wall is raised to the power1/3. It is noticed that these values $(h_{em}/Hw)^{1/3}$ is almost constant for different wall heights. Table (5.7) summarizes the values of equivalent moment height and ratio $(h_{em}/Hw)^{1/3}$ for soil group No.(1) and wall Group No. (1) for berm with zero top width. The quantity $(h_{em}/Hw)^{1/3}$ is defined as the equivalent height moment factor. Figure (5.11) presents the relationship between the equivalent height moment factor and the berm to wall height ratio for different berm top widths. Equations (4-2), (4-4), and (4-6) are used to calculate the equivalent deflection height. Following the same procedure, the ratio of equivalent deflection and wall heights raised to the power 1/4 is found to be nearly constant. Table (5.8) summarizes these results.

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		h_{em}	$(h_{em}/Hw)^{1/3}$	H_{em}	$(h_{em}/Hw)^{1/3}$	H_{em}	$(h_{em}/Hw)^{1/3}$
0.20	1 : 2	0.23	0.43	0.33	0.40	0.49	0.41
0.2	1 : 3	0.33	0.48	0.52	0.47	0.73	0.47
0.20	1 :4	0.45	0.53	0.63	0.50	0.88	0.50
0.30	1 : 2	0.48	0.54	0.74	0.53	0.96	0.52
0.30	1 : 3	0.61	0.59	0.99	0.58	1.45	0.59
03.0	1 :4	0.70	0.62	1.19	0.62	1.71	0.63
0.40	1 : 2	0.71	0.62	1.12	0.61	1.59	0.61
0.40	1 : 3	0.90	0.67	1.54	0.68	2.24	0.68
0.40	1 :4	1.01	0.70	1.74	0.70	2.37	0.70
0.50	1 : 2	0.99	0.69	1.65	0.69	2.37	0.70
0.50	1 : 3	1.23	0.74	2.06	0.74	3.01	0.75
0.50	1 :4	1.30	0.76	2.19	0.76	3.21	0.77
0.60	1 : 2	1.22	0.74	2.10	0.75	3.06	0.76
0.60	1 : 3	1.48	0.79	2.70	0.81	3.74	0.81
0.60	1 :4	1.56	0.80	2.90	0.85	3.86	0.82

Table (5.7): Comparison between Equivalent Moment Factors

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$
0.20	1 : 2	0.12	0.45	0.19	0.44	0.30	0.46
0.20	1 : 3	0.17	0.49	0.32	0.50	0.49	0.52
0.20	1 :4	0.27	0.55	0.44	0.54	0.69	0.56
0.30	1 : 2	0.26	0.54	0.50	0.56	0.66	0.56
0.30	1 : 3	0.36	0.59	0.70	0.61	1.10	0.63
0.30	1 :4	0.47	0.63	0.92	0.65	1.40	0.67
0.40	1 : 2	0.43	0.61	0.80	0.63	1.19	0.64
0.40	1 : 3	0.59	0.66	1.19	0.70	1.81	0.71
0.40	1 :4	0.78	0.71	1.49	0.74	2.07	0.74
0.50	1 : 2	0.65	0.68	1.27	0.71	1.87	0.72
0.50	1 : 3	0.95	0.75	1.73	0.77	2.58	0.78
0.50	1 :4	1.17	0.79	2.04	0.80	2.93	0.80
0.60	1 : 2	0.93	0.75	1.69	0.76	2.50	0.77
0.60	1 : 3	1.31	0.81	2.38	0.83	3.23	0.82
0.60	1 :4	1.45	0.84	2.63	0.85	3.45	0.84

Table (5.8): Comparison between Equivalent Deflection Factors

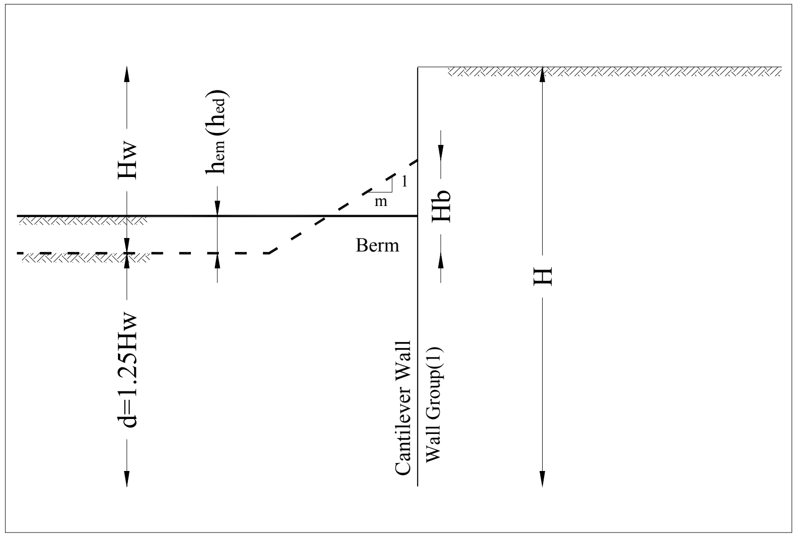


Figure (5.10): Geometry of Bermed Wall with Zero Top Width

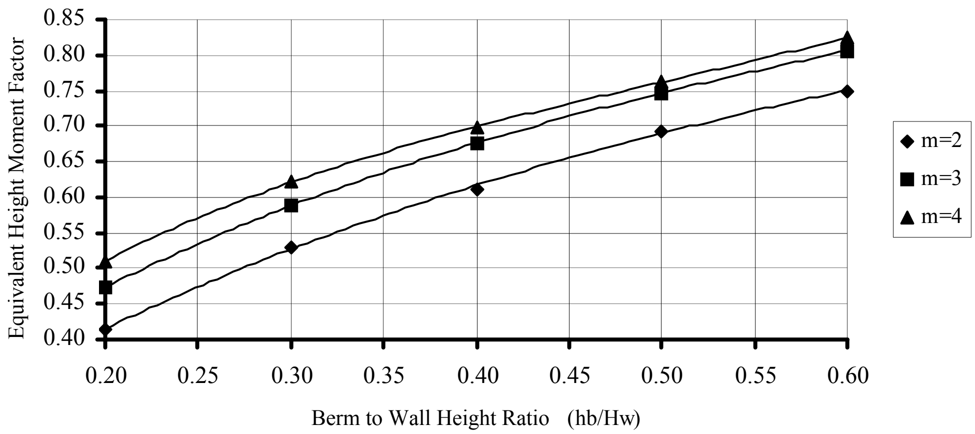


Figure (5.11): Equivalent Moment Height Factor versus Wall to Berm Height Ratio
(φ =28°&Wall Group (1))

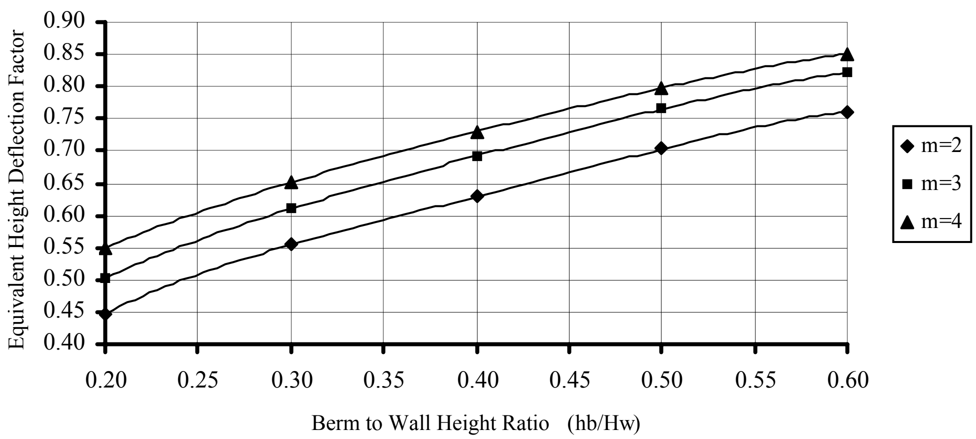


Figure (5.12): Equivalent Deflection Height Factor versus Wall to Berm Height Ratio
(φ =28°&Wall Group (1))

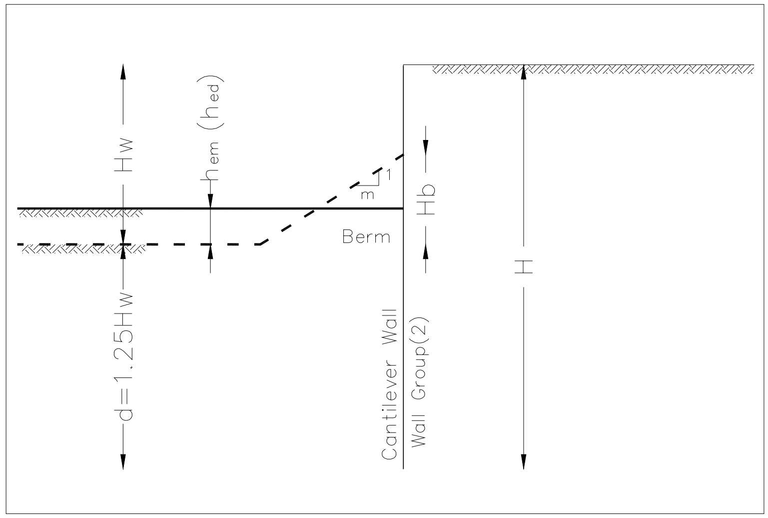


Figure (5.13): Geometry of Bermed Wall with Zero Top Width

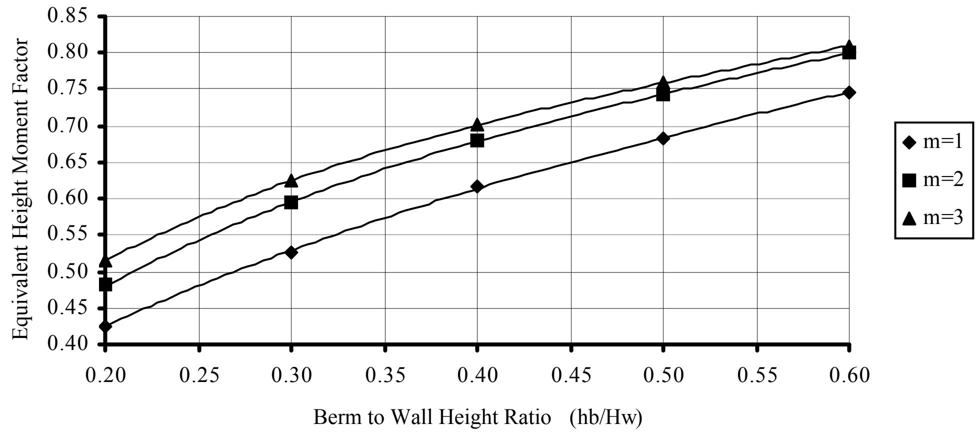


Figure (5.14): Equivalent Moment Height Factor versus Wall to Berm Height Ratio
(φ =28°&Wall Group (2))

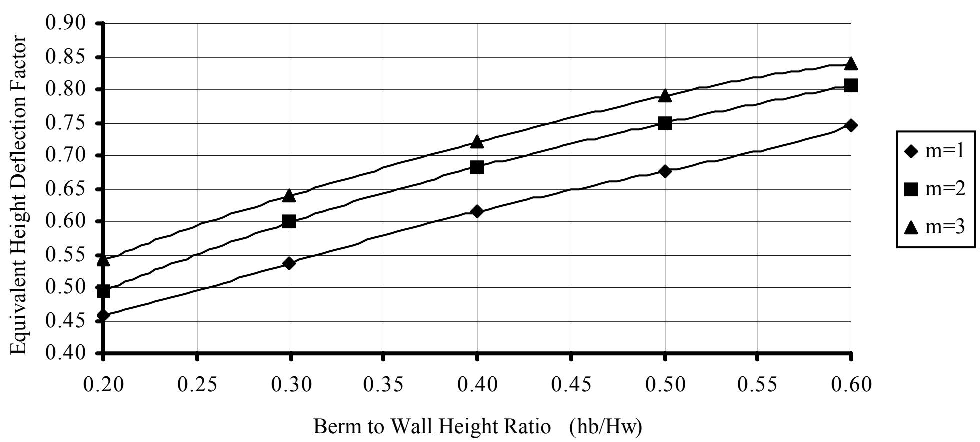


Figure (5.15): Equivalent Deflection Height Factor versus Wall to Berm Height Ratio
(φ =28°&Wall Group (2))

5.5. Equivalent Moment and Deflection Heights of Wall with Different Top Berm Widths

Equivalent moment heights for different top berm widths are calculated. The results of these analyses are summarized in Table (5.9)

Hb/Hw	.m	Bt=0.00m	Bt=1.00m	Bt=1.50m	Bt=3.00m
		$(h_{em}/Hw)^{1/3}$	$(h_{em}/Hw)^{1/3}$	$(h_{em}/Hw)^{1/3}$	$(h_{em}/Hw)^{1/3}$
0.20	1 : 2	0.41	0.48	0.53	0.57
0.2	1 : 3	0.47	0.52	0.55	0.58
0.20	1 :4	0.51	0.54	0.56	0.58
0.30	1 : 2	0.53	0.58	0.63	0.66
0.30	1 : 3	0.59	0.62	0.65	0.67
03.0	1 :4	0.62	0.65	0.66	0.67
0.40	1 : 2	0.61	0.66	0.70	0.73
0.40	1 : 3	0.68	0.70	0.73	0.74
0.40	1 :4	0.70	0.72	0.73	0.73
0.50	1 : 2	0.69	0.78	0.76	0.80
0.50	1 : 3	0.75	0.78	0.79	0.80
0.50	1 :4	0.76	0.79	0.79	0.79
0.60	1 : 2	0.75	0.79	0.83	0.83
0.60	1 : 3	0.81	0.83	0.83	0.83
0.60	1 :4	0.82	0.83	0.83	0.83

Table (5.9): Comparison between Equivalent Moment Factors For Different Top Berm Widths

Similarly, Table(5.10) presents the results of analyses performed for bermed walls having different top berm widths. Figures (5.16), (5.17) and (5.18) illustrate the wall used in the analyses, the variation of equivalent moment height factor and equivalent height deflection factor with berm to wall height ratio respectively. As may be seen from Figures (5.17) and (5.18). That is of an increasing one.

Hb/Hw	.m	Bt=0.00m	Bt=1.00m	Bt=1.50m	Bt=3.00m
		$(h_{ed}/Hw)^{1/4}$	$(h_{ed}/Hw)^{1/4}$	$(h_{ed}/Hw)^{1/4}$	$(h_{ed}/Hw)^{1/4}$
0.20	1 : 2	0.45	0.53	0.57	0.63
0.20	1 : 3	0.50	0.56	0.59	0.64
0.20	1 :4	0.55	0.59	0.61	0.64
0.30	1 : 2	0.55	0.62	0.65	0.70
0.30	1 : 3	0.61	0.65	0.68	0.73
03.0	1 :4	0.65	0.69	0.70	0.73
0.40	1 : 2	0.63	0.69	0.72	0.77
0.40	1 : 3	0.69	0.74	0.76	0.79
0.40	1 :4	0.73	0.77	0.78	0.80
0.50	1 : 2	0.70	0.76	0.78	0.83
0.50	1 : 3	0.77	0.81	0.82	0.83
0.50	1 :4	0.80	0.83	0.84	0.84
0.60	1 : 2	0.76	0.81	0.84	0.85
0.60	1 : 3	0.82	0.85	0.85	0.86
0.60	1 :4	0.85	0.85	0.86	0.86

Table (5.10): Comparison between Equivalent Deflection Factors For Different Top Berm Widths

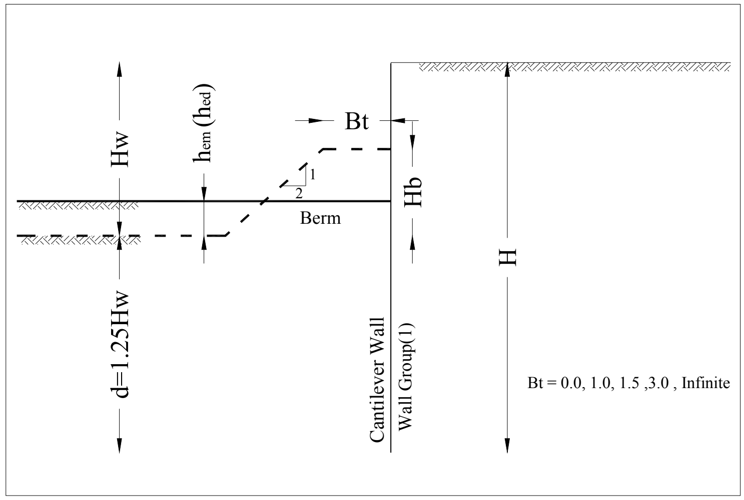


Figure (5.16): Geometry of the Bermed Wall with Different Top Berm Widths

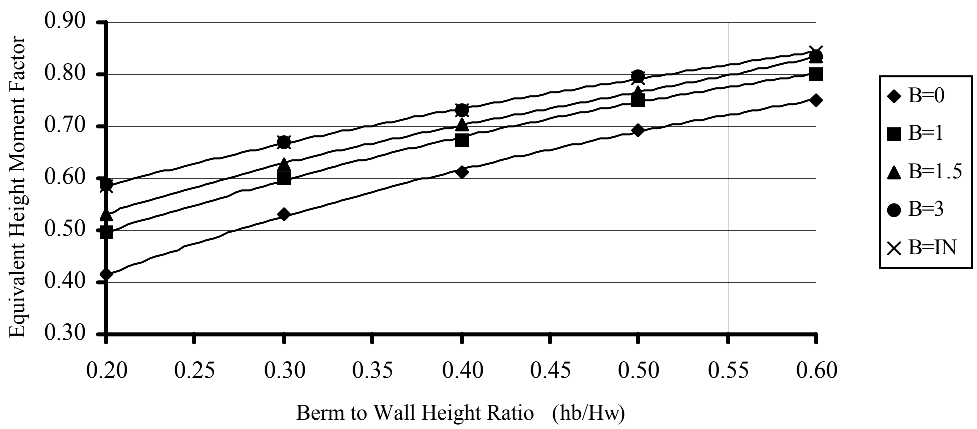


Figure (5.17): Equivalent Moment Height Factor versus Wall to Height Ratio
(φ =28° & Wall Group No. (1))

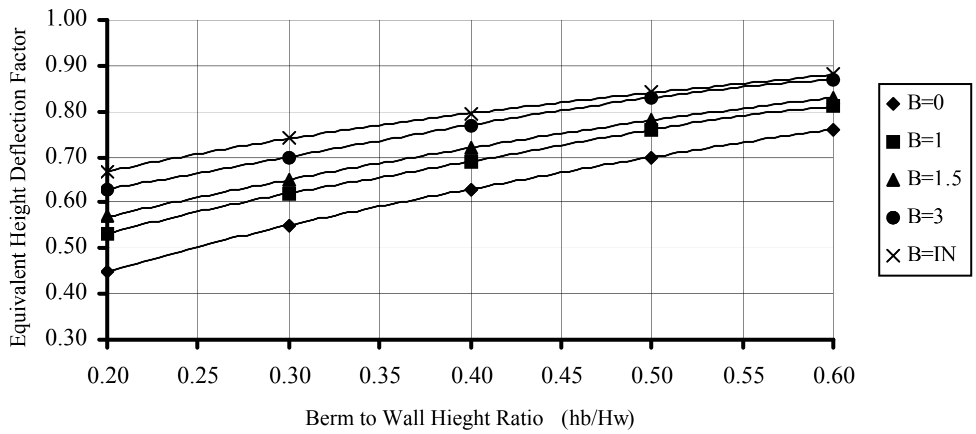


Figure (5.18): Equivalent Deflection Height Factor versus Wall to Berm Height Ratio
(φ =28° & Wall Group No. (1))

CHAPTER (6)

Limit Analysis OF Cantilever Wall

6.1. Introduction

The limit analysis of cantilever walls may be performed using the UK or USA methods. These methods are used to find the driven depth of the cantilever wall and straining actions, i.e moment and shear, at plastic failure. After estimating the driven depth, it is increased by twenty percent as a factor safety to keep the deflection of the wall within the allowable limits. When the driven depth of the wall is known, the limit analysis is used to estimate the factor of safety of the passive earth and the straining actions for this driven depth. The value of 1.5 for the factor safety is considered reasonable.

When the berm is used to increase the stability of the cantilever sheet pile wall, the limit equilibrium analysis may be performed for the wall after converting the berm to an equivalent increase in the driven depth by the approximate methods. There are two approximate methods to estimate the effect of the berm as detailed by Flemming and al., (1985).

For more accurate analysis, the passive earth pressure may be estimated using the trial wedge method. The limit equilibrium analysis is then used for calculating the straining actions on the wall.

6.2. Approximate Analysis of Cantilever Wall with Stabilizing Berm

There are two methods for considering the effect of berm on the wall. These methods convert the berm into an equivalent increase in driven depth or a surcharge load above the dredge line in front of the wall. After converting the berm, the factor of safety for passive earth pressure and straining actions on the wall are calculated using the UK or USA methods.

6.2.1. First Approximate Method of Analysis

In the first approximate method, the berm is converted into an increase in driven depth and surcharge above the dredge line as discussed in Section (2.5.1). This method can not be used if the slope of the berm is larger than 1:3.

6.2.1.1. UK Method

After converting the berm into an increase in driven depth and surcharge load, the UK method is used to estimate the straining actions on the wall. A computer program is written in Fortran 77 code to estimate the driven depth and bending moment on the wall. The code for this program is given in Appendix (1) A hand calculated example is done for verifying the results of the program. The results from the analysis using this program are presented in Tables (6.1), (6.2) and (6.3) for soil Group No.(1). The driven depth of the wall is considered 1.25 times the free height. The moment factor, Fm for the wall remains constant for the same berm to wall height ratio as shown in Table (6.4).

Note that:

H_w = Free height of the wall.

H_b/H_w = wall to berm height ratio.

m = Berm slope (1:m) VL:HL

M_{max} = Maximum bending moment on the wall.

Kp_m = Mobilized passive earth pressure coefficient.

Fs = Factor of safety for passive earth pressure.

H_w	(h_b/H_w)	(m)	(M_{max})	(Kp_m)	Fs
3.00	0.20	2	5.15	1.89	2.59
3.00	0.20	3	4.93	1.77	2.77
3.00	0.30	2	4.84	1.71	2.87
3.00	0.30	3	4.55	1.57	3.13
3.00	0.40	2	4.52	1.54	3.18
3.00	0.40	3	4.18	1.39	3.52
3.00	0.50	2	4.21	1.38	3.54
3.00	0.50	3	3.83	1.24	3.94
3.00	0.60	2	3.89	1.24	3.95
3.00	0.60	3	3.49	1.11	4.40

Table (6.1): Results from Analysis with First Approximate Method
(UK Analysis & Free Height of The Wall =3.00m)

H_w	(h_b/H_w)	(m)	(M_{max})	(Kp_m)	Fs
5.00	0.20	2	23.86	1.89	2.59
5.00	0.20	3	22.84	1.77	2.77
5.00	0.30	2	22.41	1.71	2.87
5.00	0.30	3	21.06	1.57	3.13
5.00	0.40	2	20.95	1.54	3.18
5.00	0.40	3	19.36	1.39	3.52
5.00	0.50	2	19.48	1.38	3.54
5.00	0.50	3	17.73	1.24	3.94
5.00	0.60	2	18.02	1.24	3.95
5.00	0.60	3	16.17	1.11	4.40

Table (6.2): Results from Analysis with First Approximate Method
(UK Analysis & Free Height of The Wall =5.00m)

H_w	(h_b/H_w)	(m)	(M_{max})	(Kp_m)	Fs
7.00	0.20	2	65.48	1.89	2.59
7.00	0.20	3	62.67	1.77	2.77
7.00	0.30	2	61.51	1.71	2.87
7.00	0.30	3	57.80	1.57	3.13
7.00	0.40	2	57.48	1.54	3.18
7.00	0.40	3	53.13	1.39	3.52
7.00	0.50	2	53.44	1.38	3.54
7.00	0.50	3	48.65	1.24	3.94
7.00	0.60	2	49.44	1.24	3.95
7.00	0.60	3	43.96	1.11	4.40

Table (6.3): Results from Analysis with First Approximate Method
(UK Analysis & Free Height of the Wall =7.00m)

Berm to wall height	Berm slope	Hw=3.00	Hw=5.00	Hw=7.00
Ratio (Hb/Hw)	.m	$(Mb/M)^{1/3}$	$(Mb/M)^{1/3}$	$(Mb/M)^{1/3}$
0.20	1 : 2	0.964	0.964	0.964
0.20	1 : 3	0.950	0.950	0.950
0.30	1 : 2	0.944	0.944	0.944
0.30	1 : 3	0.925	0.925	0.925
0.40	1 : 2	0.923	0.923	0.923
0.40	1 : 3	0.899	0.899	0.899
0.50	1 : 2	0.901	0.901	0.901
0.50	1 : 3	0.873	0.873	0.873
0.60	1 : 2	0.878	0.878	0.878
0.60	1 : 3	0.847	0.847	0.844

Table (6.4): Comparison between Bending Moment Ratio
(First Approximate Method & UK Analysis)

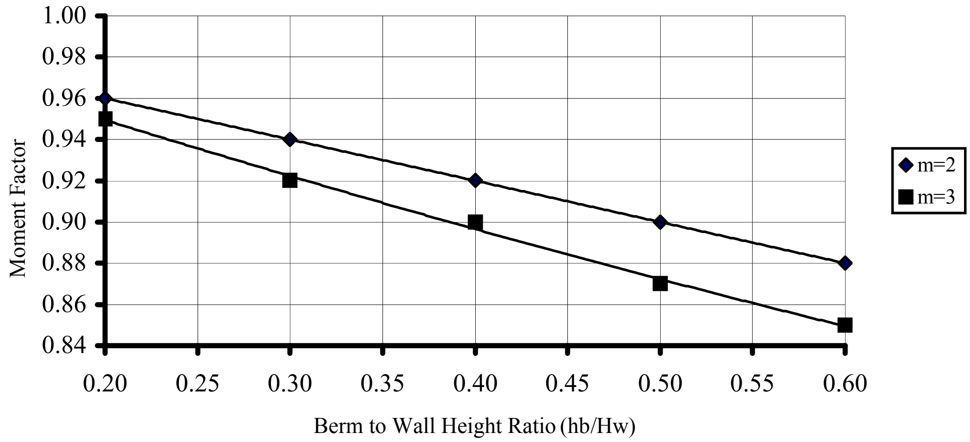


Figure (6.1): Moment Factor versus Berm to Wall Height Ratio (First Approximate Method & UK Analysis)

6.2.1.2. USA Method

Another computer program in Fortran 77 code is written to solve the cantilever sheet pile wall with the first approximate method and the analysis of the wall stability depends on USA method. This program is given in Appendix (1) and the output data of the analysis are arranged in Tables (6.5) to (6.7).

H_w	(h_b/H_w)	(m)	(M_{max})	(Kp_m)	Fs
3.00	0.20	2	5.68	1.63	3.01
3.00	0.20	3	5.41	1.50	3.26
3.00	0.30	2	5.36	1.46	3.36
3.00	0.30	3	4.97	1.30	3.77
3.00	0.40	2	5.04	1.30	3.77
3.00	0.40	3	4.53	1.12	4.39
3.00	0.50	2	4.71	1.15	4.26
3.00	0.50	3	4.11	0.96	5.10
3.00	0.60	2	4.37	1.02	4.81
3.00	0.60	3	3.70	0.83	5.94

Table (6.5): Results from Analysis with First Approximate Method (USA Analysis & Free Height of The Wall =3.00m)

H_w	(h_b/H_w)	(m)	(M_{max})	(Kp_m)	Fs
5.00	0.20	2	26.21	1.64	2.99
5.00	0.20	3	24.94	1.51	3.24
5.00	0.30	2	24.73	1.47	3.34
5.00	0.30	3	22.90	1.30	3.76
5.00	0.40	2	23.22	1.31	3.75
5.00	0.40	3	20.91	1.12	4.37
5.00	0.50	2	21.70	1.16	4.24
5.00	0.50	3	18.93	0.96	5.08
5.00	0.60	2	20.15	1.02	4.79
5.00	0.60	3	17.03	0.83	5.92

Table (6.6): Results from Analysis with First Approximate Method
(USA Analysis & Free Height of The Wall =5.00m)

H_w	(h_b/H_w)	(m)	(M_{max})	(Kp_m)	Fs
7.00	0.20	2	71.89	1.64	2.99
7.00	0.20	3	68.41	1.51	3.24
7.00	0.30	2	67.83	1.47	3.34
7.00	0.30	3	62.83	1.30	3.76
7.00	0.40	2	63.71	1.31	3.75
7.00	0.40	3	57.32	1.12	4.37
7.00	0.50	2	59.49	1.16	4.23
7.00	0.50	3	51.94	0.96	5.08
7.00	0.60	2	55.22	1.02	4.79
7.00	0.60	3	46.65	0.83	5.91

Table (6.7): Results from analysis with first approximate method
(USA Analysis & Free Height of The Wall =7.00m)

Berm to wall height	Berm slope	Hw=3.00	Hw=5.00	Hw=7.00
Ratio (Hb/Hw)	.m	$(Mb/M)^{1/3}$	$(Mb/M)^{1/3}$	$(Mb/M)^{1/3}$
0.20	1 : 2	0.967	0.966	0.966
0.20	1 : 3	0.951	0.950	0.951
0.30	1 : 2	0.948	0.948	0.948
0.30	1 : 3	0.924	0.924	0.924
0.40	1 : 2	0.929	0.928	0.928
0.40	1 : 3	0.896	0.896	0.896
0.50	1 : 2	0.908	0.907	0.907
0.50	1 : 3	0.868	0.867	0.867
0.60	1 : 2	0.886	0.885	0.885
0.60	1 : 3	0.838	0.837	0.837

Table (6.8): Comparison between Bending Moment Ratios
(First approximate method & USA analysis)

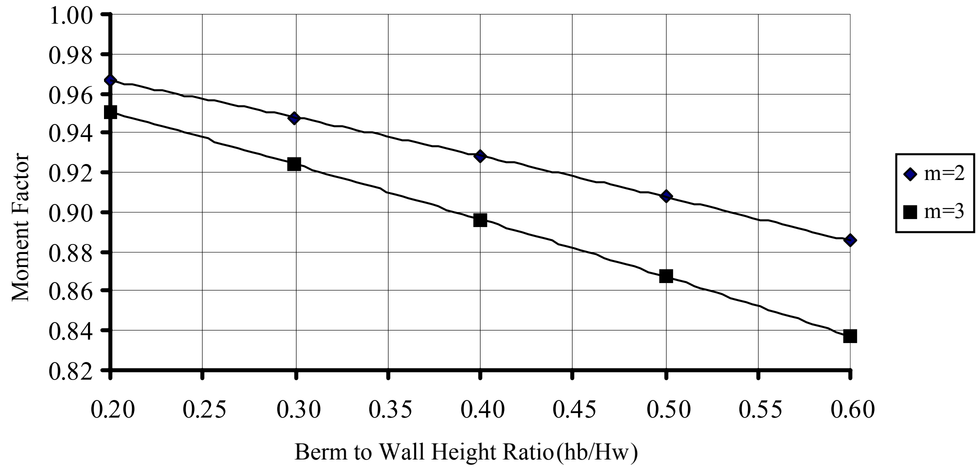


Figure (6.2): Moment Factor versus Berm to Wall Height Ratio
(First Approximate Method & USA Analysis)

6.2.2. Second Approximate Method of Analysis

In the second approximate method, the berm is converted to a surcharge on the width of the passive failure wedge as detailed in Section (2.5.2). This method gives more conservative results than the first method because it neglects the shear strength of the berm.

6.2.2.1. UK Method

Solutions using the second approximate method for the bermed wall utilizing UK method for limit equilibrium analysis has been performed. A program in Fortran 77 code is presented in Appendix (1) for this solution. Results are shown in Tables (6.9) to (6.12).

H_w	(h_b/H_w)	(m)	(M_{max})	(Kp_m)	Fs
3.00	0.20	2	5.61	2.17	2.26
3.00	0.20	3	5.55	2.11	2.32
3.00	0.20	4	5.48	2.06	2.38
3.00	0.30	2	5.46	2.03	2.41
3.00	0.30	3	5.33	1.93	2.54
3.00	0.30	4	5.22	1.83	2.68
3.00	0.40	2	5.27	1.87	2.62
3.00	0.40	3	5.09	1.72	2.86
3.00	0.40	4	4.94	1.58	3.09
3.00	0.50	2	5.07	1.70	2.89
3.00	0.50	3	4.86	1.50	3.26
3.00	0.50	4	4.69	1.35	3.63
3.00	0.60	2	4.88	1.53	3.21
3.00	0.60	3	4.64	1.31	3.75
3.00	0.60	4	4.47	1.14	4.28

Table (6.9): Results from Analysis with Second Approximate Method
(UK Analysis & Free Height of The Wall =3.00m)

H_w	(h_b/H_w)	(m)	(M_{max})	(Kp_m)	Fs
5.00	0.20	2	25.97	2.17	2.26
5.00	0.20	3	25.68	2.11	2.32
5.00	0.20	4	25.39	2.06	2.38
5.00	0.30	2	25.26	2.03	2.41
5.00	0.30	3	24.68	1.93	2.54
5.00	0.30	4	24.18	1.83	2.68
5.00	0.40	2	24.39	1.87	2.62
5.00	0.40	3	23.58	1.72	2.86
5.00	0.40	4	22.89	1.58	3.09
5.00	0.50	2	23.48	1.70	2.89
5.00	0.50	3	22.49	1.50	3.26
5.00	0.50	4	21.71	1.35	3.63
5.00	0.60	2	22.59	1.53	3.21
5.00	0.60	3	21.50	1.31	3.75
5.00	0.60	4	20.70	1.14	4.28

Table (6.10): Results from Analysis with Second Approximate Method
(UK Analysis & Free Height of The Wall =5.00m)

H_w	(h_b/H_w)	(m)	(M_{max})	(Kp_m)	Fs
7.00	0.20	2	71.27	2.17	2.26
7.00	0.20	3	70.45	2.11	2.32
7.00	0.20	4	69.67	2.06	2.38
7.00	0.30	2	69.30	2.03	2.41
7.00	0.30	3	67.74	1.93	2.54
7.00	0.30	4	66.34	1.83	2.68
7.00	0.40	2	66.94	1.87	2.62
7.00	0.40	3	64.69	1.72	2.86
7.00	0.40	4	62.82	1.58	3.09
7.00	0.50	2	64.44	1.70	2.89
7.00	0.50	3	61.70	1.50	3.26
7.00	0.50	4	59.57	1.35	3.63
7.00	0.60	2	61.99	1.53	3.21
7.00	0.60	3	58.99	1.31	3.75
7.00	0.60	4	56.80	1.14	4.28

Table (6.11): Results from Analysis with Second Approximate Method
(UK Analysis & Free Height of The Wall =7.00m)

Berm to wall height	Berm slope	Hw=3.00	Hw=5.00	Hw=7.00
Ratio (Hb/Hw)	.m	$(Mb/M)^{1/3}$	$(Mb/M)^{1/3}$	$(Mb/M)^{1/3}$
0.20	1 : 2	0.992	0.992	0.992
0.20	1 : 3	0.988	0.988	0.988
0.20	1 : 4	0.984	0.984	0.984
0.30	1 : 2	0.983	0.983	0.983
0.30	1 : 3	0.975	0.975	0.975
0.30	1 : 4	0.968	0.968	0.968
0.40	1 : 2	0.971	0.971	0.971
0.40	1 : 3	0.960	0.960	0.960
0.40	1 : 4	0.951	0.951	0.951
0.50	1 : 2	0.959	0.959	0.959
0.50	1 : 3	0.945	0.945	0.945
0.50	1 : 4	0.934	0.934	0.934
0.60	1 : 2	0.947	0.947	0.947
0.60	1 : 3	0.931	0.931	0.931
0.60	1 : 4	0.919	0.919	0.920

Table (6.12): Comparison between Bending Moment Ratio
(Second Approximate Method & UK Analysis)

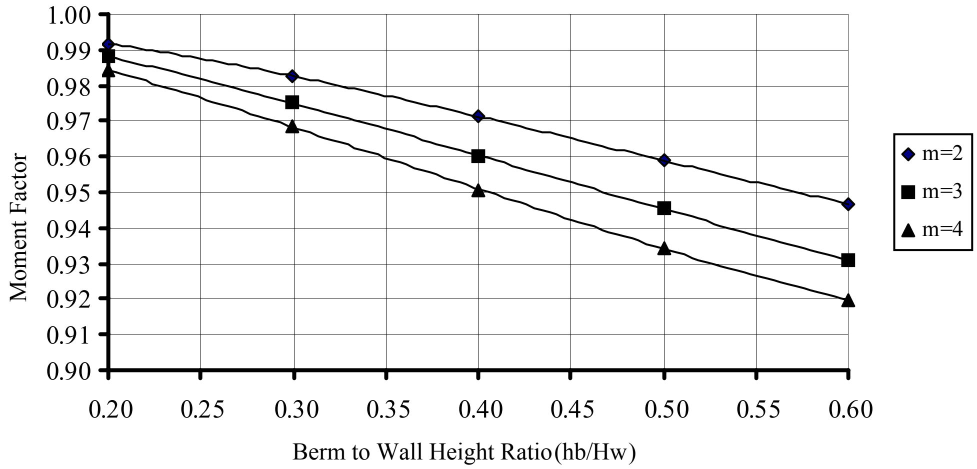


Figure (6.3): Moment Factor versus Berm to Wall Height Ratio
(Second Approximate Method & UK Analysis)

6.2.2.2. USA Method

Another computer program in Fortran 77 code is written for the analysis of cantilever wall with second approximate method and USA method of stability. The code of the program is given in Appendix (1). The results of the analysis are arranged in Tables (6.13) to (6.16).

H_w	(h_b/H_w)	(m)	(M_{max})	(Kp_m)	Fs
3.00	0.20	2	6.21	1.88	2.60
3.00	0.20	3	6.17	1.84	2.66
3.00	0.20	4	6.13	1.80	2.72
3.00	0.30	2	6.11	1.78	2.75
3.00	0.30	3	6.01	1.70	2.88
3.00	0.30	4	5.90	1.62	3.02
3.00	0.40	2	5.95	1.66	2.96
3.00	0.40	3	5.76	1.53	3.19
3.00	0.40	4	5.55	1.43	3.43
3.00	0.50	2	5.73	1.52	3.22
3.00	0.50	3	5.40	1.37	3.59
3.00	0.50	4	5.03	1.24	3.95
3.00	0.60	2	5.44	1.38	3.55
3.00	0.60	3	4.90	1.21	4.07
3.00	0.60	4	4.28	1.07	4.58

Table (6.13): Results from Analysis with Second Approximate Method
(USA Analysis & Free Height of The Wall=3.00m)

H_w	(h_b/H_w)	(m)	(M_{max})	(Kp_m)	Fs
5.00	0.20	2	28.68	1.89	2.59
5.00	0.20	3	28.49	1.85	2.65
5.00	0.20	4	28.29	1.81	2.71
5.00	0.30	2	28.19	1.79	2.74
5.00	0.30	3	27.73	1.71	2.87
5.00	0.30	4	27.24	1.63	3.00
5.00	0.40	2	27.47	1.66	2.95
5.00	0.40	3	26.57	1.54	3.18
5.00	0.40	4	25.60	1.44	3.41
5.00	0.50	2	26.46	1.53	3.21
5.00	0.50	3	24.90	1.37	3.57
5.00	0.50	4	23.19	1.25	3.94
5.00	0.60	2	25.09	1.39	3.53
5.00	0.60	3	22.60	1.22	4.05
5.00	0.60	4	19.72	1.08	4.56

Table (6.14): Results from Analysis with Second Approximate Method
(USA Analysis & Free Height of The Wall =5.00m)

H_w	(h_b/H_w)	(m)	(M_{max})	(Kp_m)	Fs
7.00	0.20	2	78.66	1.89	2.59
7.00	0.20	3	78.13	1.85	2.65
7.00	0.20	4	77.61	1.81	2.71
7.00	0.30	2	77.32	1.79	2.74
7.00	0.30	3	76.06	1.71	2.87
7.00	0.30	4	74.72	1.63	3.00
7.00	0.40	2	75.34	1.66	2.95
7.00	0.40	3	72.88	1.54	3.18
7.00	0.40	4	70.21	1.44	3.41
7.00	0.50	2	72.55	1.53	3.21
7.00	0.50	3	68.27	1.37	3.57
7.00	0.50	4	63.58	1.25	3.93
7.00	0.60	2	68.80	1.39	3.53
7.00	0.60	3	61.96	1.21	4.05
7.00	0.60	4	54.10	1.08	4.56

Table (6.15): Results from Analysis with Second Approximate Method
(USA Analysis & Free Height of The Wall =7.00m)

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Mb/M)^{1/3}$	Hw=5.00 $(Mb/M)^{1/3}$	Hw=7.00 $(Mb/M)^{1/3}$
0.20	1 : 2	0.996	0.996	0.996
0.20	1 : 3	0.994	0.994	0.994
0.20	1 : 4	0.991	0.991	0.991
0.30	1 : 2	0.990	0.990	0.990
0.30	1 : 3	0.985	0.985	0.985
0.30	1 : 4	0.979	0.979	0.979
0.40	1 : 2	0.982	0.982	0.982
0.40	1 : 3	0.971	0.971	0.971
0.40	1 : 4	0.959	0.959	0.959
0.50	1 : 2	0.969	0.969	0.969
0.50	1 : 3	0.950	0.950	0.950
0.50	1 : 4	0.928	0.928	0.928
0.60	1 : 2	0.953	0.952	0.952
0.60	1 : 3	0.920	0.920	0.920
0.60	1 : 4	0.880	0.879	0.879

Table (6.16): Comparison between Bending Moment Ratio (Second Approximate Method & USA Analysis)

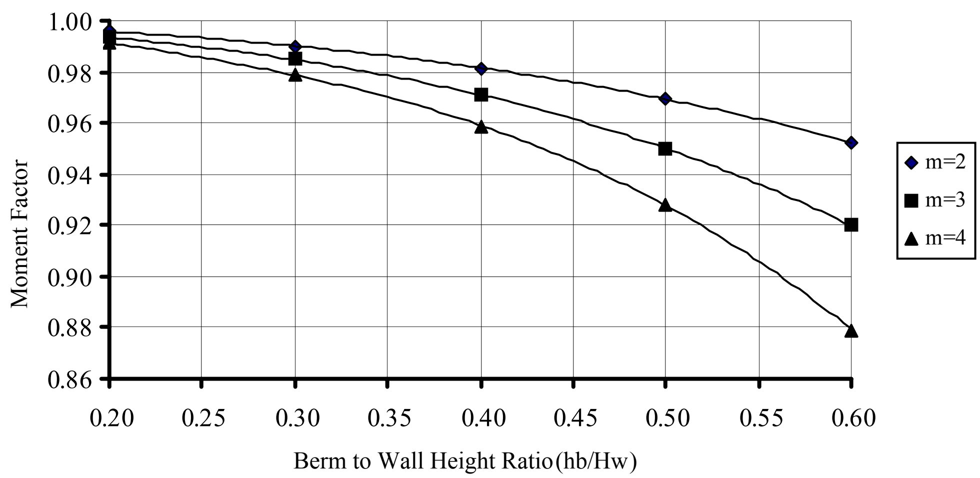


Figure (6.4): Moment Factor versus Berm to Wall Height Ratio (Second Approximate Method & USA Analysis)

6.3. Trial Wedge Analysis for Bermed Cantilever Wall

The trail wedge method as described by Coulomb is used to find the failure plane on the passive side for cantilever wall with stabilizing berm. The passive earth pressure force is determined from the stability of the failure wedge. The passive earth pressure coefficient is estimated from the passive force assuming triangular distribution of passive earth pressure. The mobilized earth pressure coefficient is determined from the stability of the cantilever wall considering the driven depth equal the depth below the dredge line plus the berm height.

6.3.1. UK Method

The stability analysis of the wall is performed using the UK method to find the factor of safety for passive earth pressure and the maximum bending moment on the wall. A computer program in Fortran 77 code is written for the analysis of the wall. The code of program is given in Appendix (1). The input and output data of the analysis are summarized in Tables (6.17) to (6.20).

H_w	(h_b/H_w)	(m)	θ	(M_{max})	(Kp_m)	Fs
3.00	0.20	2	71	4.19	1.40	2.63
3.00	0.20	3	71	4.19	1.40	2.66
3.00	0.20	4	71	4.19	1.40	2.68
3.00	0.30	2	71	3.50	1.12	2.95
3.00	0.30	3	71	3.50	1.12	3.01
3.00	0.30	4	72	3.50	1.12	3.06
3.00	0.40	2	72	2.86	0.90	3.32
3.00	0.40	3	72	2.86	0.90	3.42
3.00	0.40	4	72	2.86	0.90	3.52
3.00	0.50	2	72	2.28	0.74	3.74
3.00	0.50	3	73	2.28	0.74	3.91
3.00	0.50	4	73	2.28	0.74	4.08
3.00	0.60	2	73	1.74	0.61	4.22
3.00	0.60	3	73	1.74	0.61	4.48
3.00	0.60	4	74	1.74	0.61	4.73

Table (6.17): Results from Analysis with Trail Wedge Method
(UK analysis & free height of the wall =3.00m)

H_w	(h_b/H_w)	(m)	θ	(M_{max})	(Kp_m)	Fs
5.00	0.20	2	71	19.38	1.40	2.64
5.00	0.20	3	71	19.38	1.40	2.67
5.00	0.20	4	71	19.38	1.40	2.69
5.00	0.30	2	71	16.18	1.11	2.96
5.00	0.30	3	71	16.18	1.11	3.02
5.00	0.30	4	72	16.18	1.11	3.07
5.00	0.40	2	72	13.24	0.90	3.33
5.00	0.40	3	72	13.24	0.90	3.43
5.00	0.40	4	72	13.24	0.90	3.54
5.00	0.50	2	72	10.54	0.74	3.75
5.00	0.50	3	73	10.54	0.74	3.92
5.00	0.50	4	73	10.54	0.74	4.09
5.00	0.60	2	73	8.05	0.61	4.23
5.00	0.60	3	73	8.05	0.61	4.49
5.00	0.60	4	74	8.05	0.61	4.75

Table (6.18): Results from Analysis with Trail Wedge Method
(UK analysis & Free Height of The Wall =5.00m)

H_w	(h_b/H_w)	(m)	θ	(M_{max})	(Kp_m)	Fs
7.00	0.20	2	71	53.23	1.40	2.63
7.00	0.20	3	71	53.23	1.40	2.66
7.00	0.20	4	71	53.23	1.40	2.68
7.00	0.30	2	71	44.44	1.12	2.95
7.00	0.30	3	71	44.44	1.12	3.01
7.00	0.30	4	72	44.44	1.12	3.06
7.00	0.40	2	72	36.36	0.90	3.32
7.00	0.40	3	72	36.36	0.90	3.42
7.00	0.40	4	72	36.36	0.90	3.52
7.00	0.50	2	72	28.94	0.74	3.74
7.00	0.50	3	73	28.94	0.74	3.91
7.00	0.50	4	73	28.94	0.74	4.08
7.00	0.60	2	73	22.12	0.61	4.22
7.00	0.60	3	73	22.12	0.61	4.48
7.00	0.60	4	74	22.12	0.61	4.73

Table (6.19): Results from Analysis with Trail Wedge Method
(UK Analysis & Free Height of The Wall =7.00m)

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Mb/M)^{1/3}$	Hw=5.00 $(Mb/M)^{1/3}$	Hw=7.00 $(Mb/M)^{1/3}$
0.20	1 : 2	0.900	0.899	0.900
0.20	1 : 3	0.900	0.899	0.900
0.20	1 : 4	0.900	0.899	0.900
0.30	1 : 2	0.847	0.847	0.847
0.30	1 : 3	0.847	0.847	0.847
0.30	1 : 4	0.847	0.847	0.847
0.40	1 : 2	0.792	0.792	0.792
0.40	1 : 3	0.792	0.792	0.792
0.40	1 : 4	0.792	0.792	0.792
0.50	1 : 2	0.735	0.734	0.734
0.50	1 : 3	0.735	0.734	0.734
0.50	1 : 4	0.735	0.734	0.734
0.60	1 : 2	0.671	0.671	0.671
0.60	1 : 3	0.671	0.671	0.671
0.60	1 : 4	0.671	0.671	0.671

Table (6.20): Comparison between Bending Moment Ratio (Trial Wedge Analysis & UK Analysis)

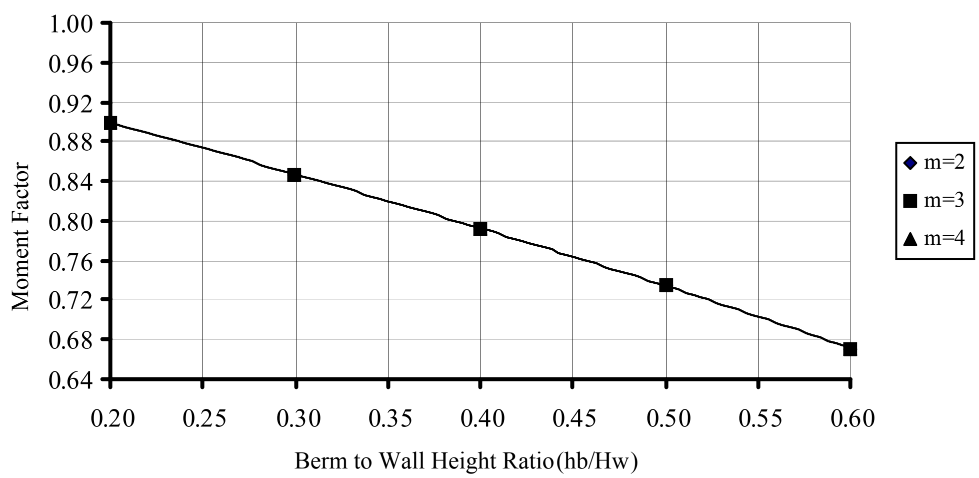


Figure (6.5): Moment Factor versus Berm to Wall Height Ratio (Trail Wedge Method & UK Analysis)

6.3.2. USA Method

Another program for the analysis of cantilever wall with stabilizing berm is written to estimate the straining actions on the wall. This program depends on the USA method of analysis. The code of the program is given in Appendix (1). The output data of the analysis are summarized in Tables (6.21) to (6.24).

H_w	(h_b/H_w)	(m)	θ	(M_{max})	(Kp_m)	Fs
3.00	0.20	2	71	4.46	1.31	2.82
3.00	0.20	3	71	4.46	1.31	2.84
3.00	0.20	4	71	4.46	131	2.87
3.00	0.30	2	71	3.53	1.11	2.98
3.00	0.30	3	71	3.53	1.11	3.03
3.00	0.30	4	72	3.53	1.11	3.09
3.00	0.40	2	72	2.85	0.91	3.30
3.00	0.40	3	72	2.85	0.91	3.41
3.00	0.40	4	72	2.85	0.91	3.51
3.00	0.50	2	72	2.47	0.71	3.90
3.00	0.50	3	73	2.47	0.71	4.08
3.00	0.50	4	73	2.47	0.71	4.26
3.00	0.60	2	73	1.76	0.61	4.24
3.00	0.60	3	73	1.76	0.61	4.50
3.00	0.60	4	74	1.76	0.61	4.75

Table (6.21): Results from Analysis with Trail Wedge Method
(USA Analysis & Free Height of The Wall =3.00m)

H_w	(h_b/H_w)	(m)	θ	(M_{max})	(Kp_m)	Fs
5.00	0.20	2	71	20.60	1.31	2.83
5.00	0.20	3	71	20.60	1.31	2.85
5.00	0.20	4	71	20.60	131	2.88
5.00	0.30	2	71	16.34	1.11	2.99
5.00	0.30	3	71	16.34	1.11	3.04
5.00	0.30	4	72	16.34	1.11	3.10
5.00	0.40	2	72	13.16	0.91	3.31
5.00	0.40	3	72	13.16	0.91	3.42
5.00	0.40	4	72	13.16	0.91	3.52
5.00	0.50	2	72	11.42	0.71	3.91
5.00	0.50	3	73	11.42	0.71	4.10
5.00	0.50	4	73	11.42	0.71	4.27
5.00	0.60	2	73	8.13	0.61	4.25
5.00	0.60	3	73	8.13	0.61	4.51
5.00	0.60	4	74	8.13	0.61	4.77

Table (6.22): Results from Analysis with Trail Wedge Method
(USA Analysis & Free Height of The Wall =5.00m)

H_w	(h_b/H_w)	(m)	θ	(M_{max})	(Kp_m)	Fs
7.00	0.20	2	71	56.60	1.31	2.82
7.00	0.20	3	71	56.60	1.31	2.84
7.00	0.20	4	71	56.60	131	2.87
7.00	0.30	2	71	44.89	1.11	2.98
7.00	0.30	3	71	44.89	1.11	3.03
7.00	0.30	4	72	44.89	1.11	3.09
7.00	0.40	2	72	36.16	0.91	3.30
7.00	0.40	3	72	36.16	0.91	3.41
7.00	0.40	4	72	36.16	0.91	3.51
7.00	0.50	2	72	31.38	0.71	3.90
7.00	0.50	3	73	31.38	0.71	4.08
7.00	0.50	4	73	31.38	0.71	4.26
7.00	0.60	2	73	22.35	0.61	4.24
7.00	0.60	3	73	22.35	0.61	4.50
7.00	0.60	4	74	22.35	0.61	4.75

Table (6.23): Results from Analysis with Trail Wedge Method
(USA Analysis & Free Height of The Wall =7.00m)

Berm to wall height	Berm slope	Hw=3.00	Hw=5.00	Hw=7.00
Ratio (Hb/Hw)	.m	$(Mb/M)^{1/3}$	$(Mb/M)^{1/3}$	$(Mb/M)^{1/3}$
0.20	1 : 2	0.892	0.892	0.892
0.20	1 : 3	0.892	0.892	0.892
0.20	1 : 4	0.892	0.892	0.892
0.30	1 : 2	0.825	0.825	0.826
0.30	1 : 3	0.825	0.825	0.826
0.30	1 : 4	0.825	0.825	0.826
0.40	1 : 2	0.768	0.768	0.769
0.40	1 : 3	0.768	0.768	0.769
0.40	1 : 4	0.768	0.768	0.769
0.50	1 : 2	0.732	0.733	0.733
0.50	1 : 3	0.732	0.733	0.733
0.50	1 : 4	0.732	0.733	0.733
0.60	1 : 2	0.654	0.654	0.655
0.60	1 : 3	0.654	0.654	0.655
0.60	1 : 4	0.654	0.654	0.655

Table (6.24): Comparison between Bending Moment Ratio
(Trial Wedge Analysis & USA Analysis)

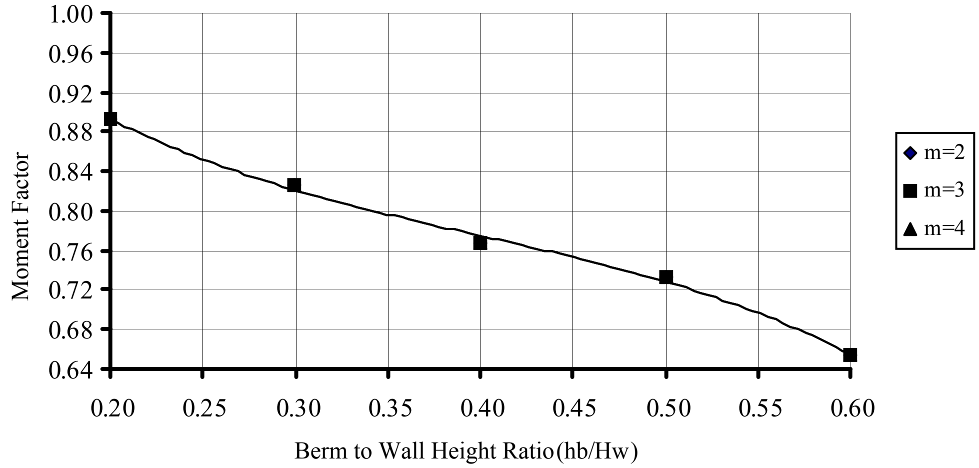


Figure (6.6) Moment Factor versus Wall to Height Ratio
(Trail Wedge Method & USA Analysis)

6.4. Comparison between Limit Equilibrium and Finite Element Analyses

The results of the different limit equilibrium methods are compared with the finite element results. The finite element method gives approximately the same results as the trail wedge method but the results of the approximate methods give results more conservative especially the second approximate method. The results of the different methods of analysis for berm slope 1:2 and soil Group No.(1) are summarized in Figures (6.7) t o (6.8). The approximate methods may be corrected by multiplying by correction factor. This correction is related to the berm to wall height ratio. The value of correction factors are summarized in Table (6.25)

Berm Approximation	Method of Analysis	Correction factor
1st approximate method	UK method	(1.0 - 0.50*hb/Hw)
1st approximate method	USA method	(1.0 - 0.70*hb/Hw)
2nd approximate method	UK method	(1.0 – 0.80*hb/Hw)
2nd approximate method	USA method	(1.0 – hb/Hw)

Table (6.25): Correction Factors for Approximate Methods

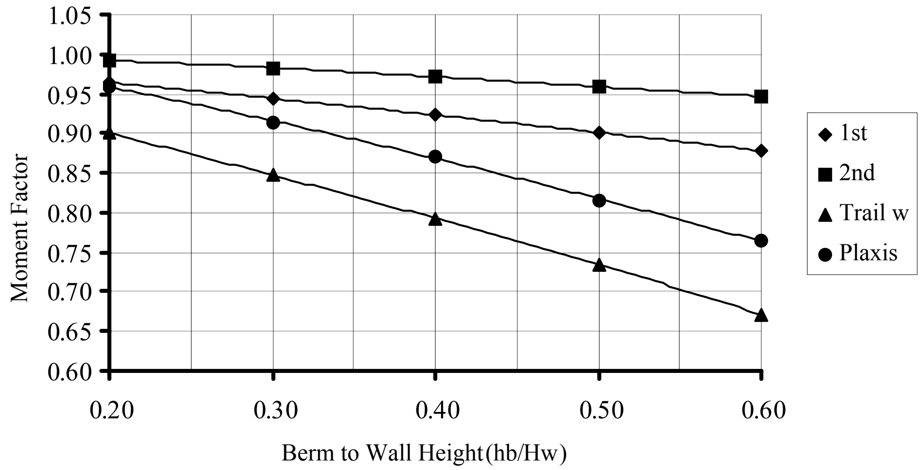


Figure (6.7): Moment Factor versus Berm to Wall Height Ratio
(UK Analysis & Finite Element Analysis)

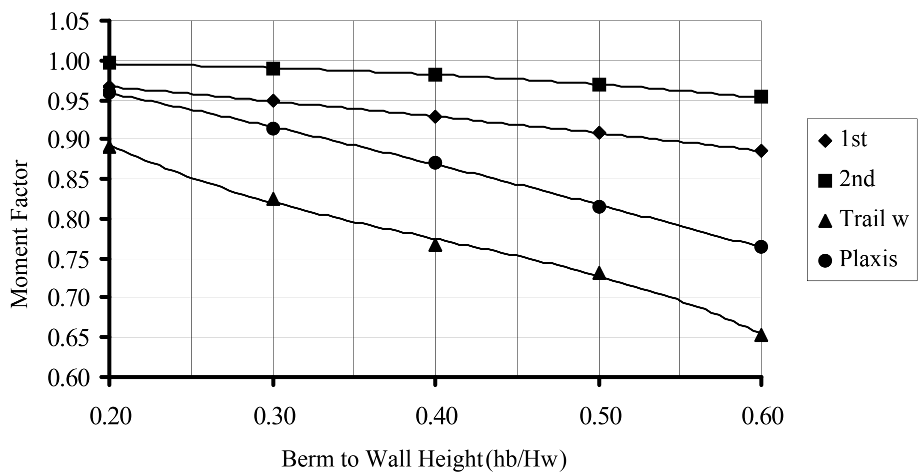


Figure (6.8): Moment Factor versus Wall to Height Ratio
(USA Analysis & Finite Element Analysis)

CHAPTER (7)

LABORATORY WORK

7.1. Introduction

Laboratory work is made for the verification the finite element analysis of a cantilever wall with berm. The comparison is done between wall deflections obtained from experimental work and deflections obtained from numerical analysis. A testing tank with sensitive dail guages for measurement displacemts was built in the laboratory. A suitable uniform sand without fine materials is selected to be used in the tests. Before testing, the mechanical and physical properties of the sand were determined.

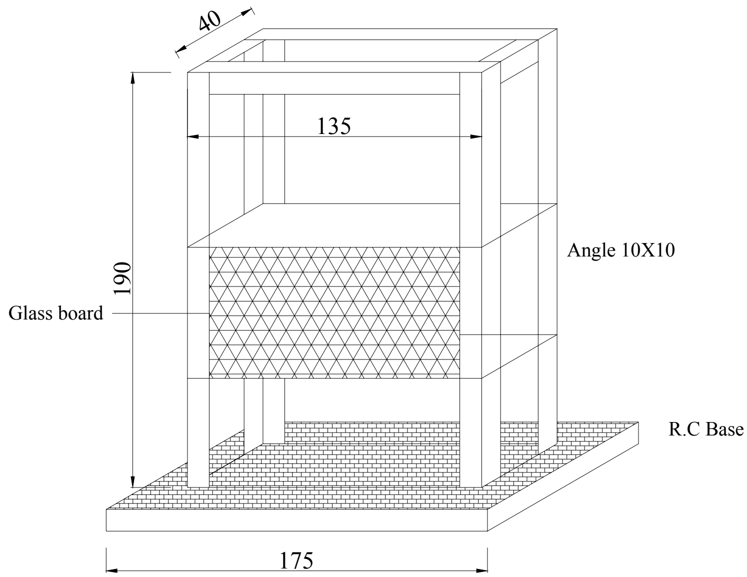
The tests were performed for two samples having different relative densites. For both sands, different berm geometries were constructed in the tank

7.2. Testing Tank

The testing tank was built of rigid steel plates, angles and channels assembled together to render the tank stiff configuration keeping the sand-bed in an undisturbed state during the test. The details of the tank are given in Figure (7.1)

The tank dimensions are 250mm X 1200mm X 600mm deep. The dimensions are found to be large enough to minimize boundary effects resulted from the shear stresses developing between the sides and the soil.

The tank sides are composed of 2mm steel plates connected with angles 45mm X 5mm the angles of the tank sides were connected together with 5mm bolts at 50mm spacing. Membrane material is placed between the angles to prevent any fine soil to escaping from the sides. The tank is supported by a rigid steel frame as shown in attached photos in Appendix (6). One side of the tank that has dimensions 1200mm X 600mm is made of 3mm glass board to help in excavating the soil in front of wall and form the berm.



Figure(7.1): Configuration of the Testing Tank

7.3. Cantilver Wall Model

The model is a stainless steel plate having the following properties:

Thickness of sheet-pile model, tm = 1.5mm

The inertia of the model, Im = 2.8125E-10m^3/m'

Free height of the model = 350mm

Driven depth of the model = 245mm

7.4. Physical and Mechanical Properties of the Tested Sand

The sand used in the tests is clean siliceous yellow sand. It is air dried and sieved through B.S. sieve No. 16, 1.003mm, to remove any impurities or large particles. To reduce the amount of dust arising during the deposition process all the sand is sieved over B.S. sieve No. 200. This operation separates most of the particles finer than 0.074mm diameter.

7.4.1. Specific Gravity

The specific gravity, Gs, of the sand particles is determined for 5 representative samples according to ECP.(2.8) . The mean specific gravity obtained is 2.64 ± 0.02.

7.4.2. Grain Size Distribution

Mechanical analyses were performed according to ECP.(2.9) using the method of coarse analysis by dry sieving. The gradation curve of a tested sample is given in Figure (7.2). From the gradation curve, it can be seen that the tested sand is a fine to medium sand with mean average grain size, D_{50}, equal to 0.3mm and having a mean coefficient of uniformity, D_{60}/D_{10}, equal to 2.00. Therefore, the sand is considered to be fairly uniform. This uniformity of particles is desirable in the tested sand, as it makes the deposited sand masses a homogeneous structure.

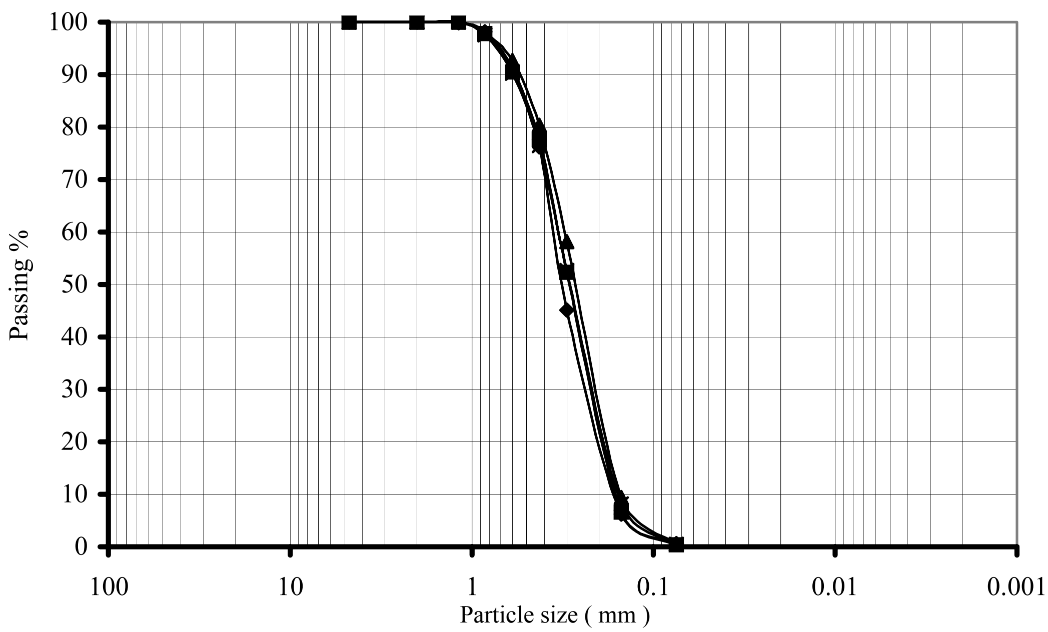


Figure (7.2): Grain Size Distribution of the Tested Sand

7.4.3. Moisture Content

The moisture content, Wc, was determined, according to ECP.(2.2) using the standard method, for 12 air-dried samples. The results of the water content tests are presented in Table (7.1). From the results, the moisture content is found to be 0.31%±0.025%.

Wt (container, dry soil)	Wt (container, wet soil)	Wt (container)	Wc %
75.69	75.54	19.64	0.27
101.88	101.63	19.54	0.30
103.48	103.19	15.48	0.33
89.51	89.24	14.40	0.36
121.08	120.79	28.56	0.31
94.78	94.52	17.73	0.34
94.95	94.73	19.29	0.29
71.47	71.31	19.91	0.31
153.09	152.73	29.25	0.29
147.94	147.56	32.84	0.33
146.21	145.81	19.64	0.32
80.70	80.51	15.32	0.29

Table (7.1): Results of Water Content Tests

7.4.4. Maximum Porosity

The maximum porosity, $n_{max,}$ of the tested sand is determined by the funnel method. In this test the oven-dried sand is poured from a funnel having a nozzle of ¼" internal diameter, and the end of nozzle is kept at level ¼" higher than the rising surface of the deposited sand. The test, performed on 12 samples gave a maximum value for the porosity equals 45.5% corresponding to a minimum dry density equals 14.39 kN/m^3.

7.4.5. Minimum Porosity

The minimum porosity, n_{min}, for the test sand was determined, for the 12 sand samples used minimum porosity determination according to the method suggested by Akroyed . The test is carried out by placing sufficient material in the mould, so that after compaction it is 1/3 full. Then, the material is compacted for about 1.5minutes using a hammer. Two more layers of soil are filled into the mould, and each layer is, in turn compacted by the same manner.

These tests give the least value for minimum porosity which equals 31.0%, where the maximum dry density is 18.22kN/m^3.

7.4.5. Shear Strength

The shear strength of tested sand can be determined using the direct shear box or by the triaxial test. The details of these methods are discussed in ECP.(2.24). The direct shear test is used for determination of the angle of friction for the tested sand.

7.4.5.1. The Direct Shear Tests

In these tests, the 6cm square standard shear box is used. Air dry samples are tested, at six relative densities, and under different normal pressures. The shearing force is applied at a constant rate of strain where the movable carriage is sliding at constant velocity of 0.84 mm/minutes.

The relationship between the angle of internal friction, φ, and the sand relative density, Dr, obtained is shown in Figure (7.3).

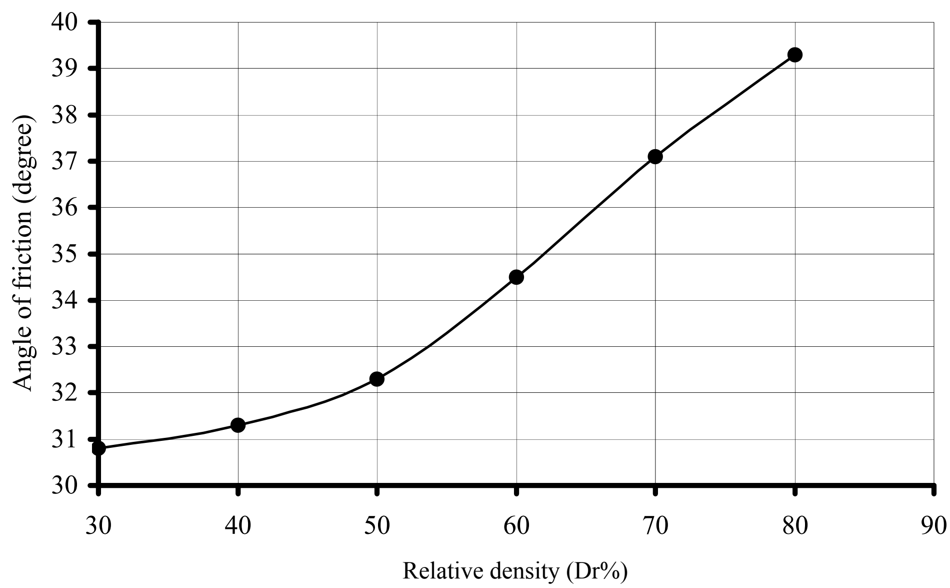


Figure (7.3): Relation between Relative Density and Angle of Friction

7.4.6. Skin Friction of Sheet-Pile Model

The angle of friction between the sand particles and the material of the model wall, δ, is determined by the means of a modified shear box apparatus. This is done by preparing a sample of the same material of the wall with its surface finished to the same degree of roughness and cut to fit precisely into the lower half of the shear box, keeping its finished surface flush with the edge of the lower half of the shear box. Sand is then poured into the upper half of the box and adjusted to the required porosity. The loading plate is placed over the leveled surface of the sand. The test is performed at two sand relative density 47% and 65%.

The angle of wall friction, δ, is calculated using the peak and residual shear stresses values, see Figures (7.4) and (7.5). For a relative density of 47%, the angle of wall friction is 20.80° using peak values of the shear stresses. For relative density of 65%, angle of wall friction is 23.40°. While, for a relative density of 47% and 65%, the angle of friction between the soil and the wall is 18.90° and 21.70°, respectively using residual value of shear stresses.

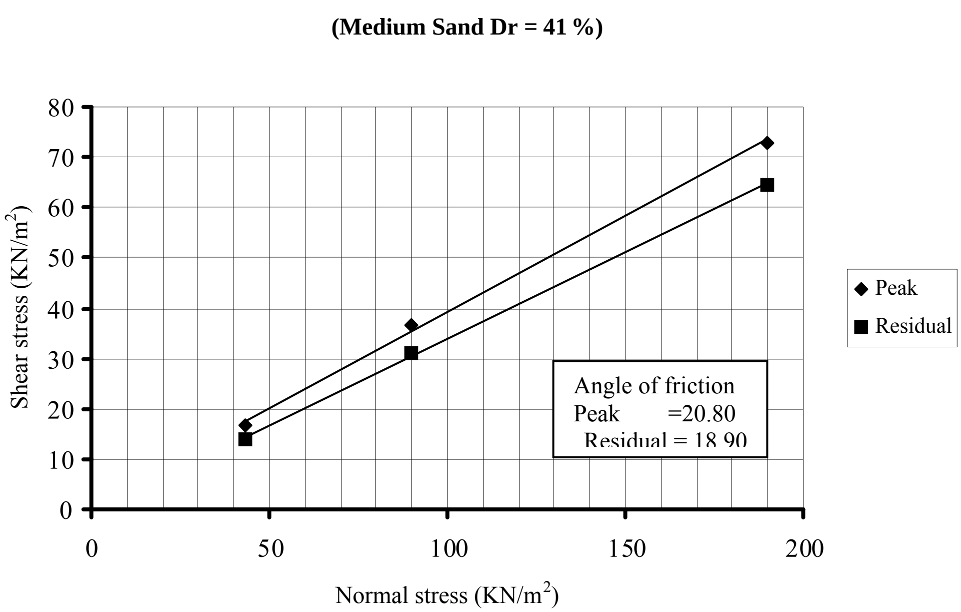


Figure (7.4): Relation between Normal and Shear Stresses (Friction between Tested Sand and Model Steel Plate)

(Dense Sand Dr = 71 %)

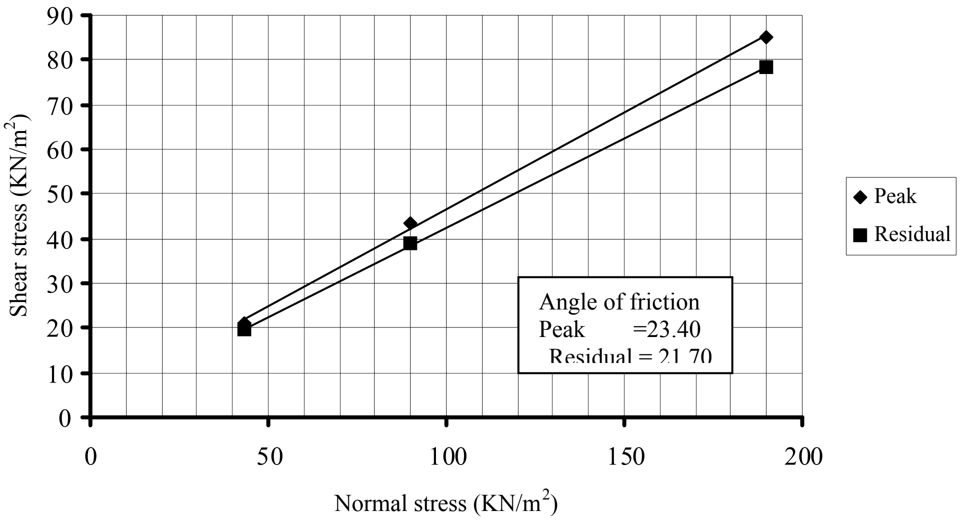


Figure (7.5): Relation between Normal and Shear Stresses
(Friction between Tested Sand and Model Steel Plate)

7.5. Adopted Method for Deposition of Sand in Testing Tank

The testing program is performed on two sand relative densities. A loose packing of relative density about 47% and a dense packing of relative density is about 65%. The loose packing could be obtained by depositing the sand into the tank in horizontal layers of 100mm thick each. The sand is deposited from height of 200mm. The dense packing could be obtained by compaction of the loose depositing sand in layers.

7.6. Measurement Technique

The deflection of the top point of the wall was measured. Four dial gauges are used for the measurement. Every two dials were placed on the same horizontal level. The level of the dail guage pairs are higher than the surface of the backfill in front of the wall. The average reading for each two dials on the same level is calculated. The two readings for the different levels were divided by the distance between the two levels to find the angle of rotation of the wall. The deflection of the top point of the wall was calculated from the rotation angle of the wall. Figure (7.6) illustrates the positions of the dials along the wall extension .

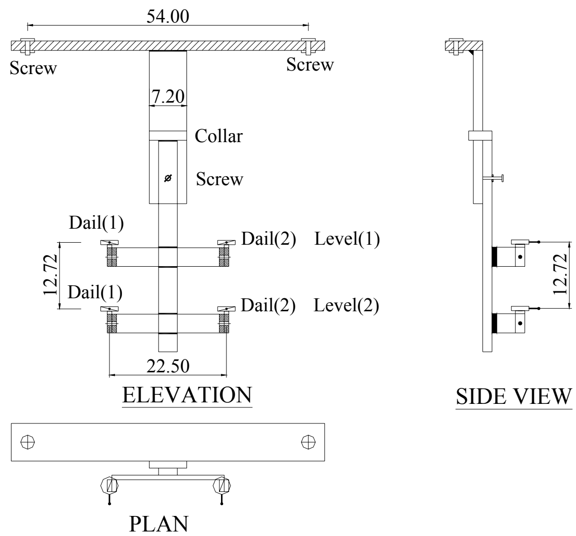


Figure (7.6): Dimensions of Measurement Apparatus

7.6. Results of Laboratory Tests and Finite Element Comparison

The results of the laboratory tests for samples with different relative density are summarized inTables (7.2) and (7.3).

Where:

1: m : Berm slope (VL : HL)

D(1) : Dial reading for dial No. (1) at level (1)

D(2) : Dial reading for dial No. (2) at level (1)

D(2) : Dial reading for dial No. (1) at level (2)

D(2) : Dial reading for dial No. (2) at level (2)

d : Distance between the two levels of dials

D : Deflection of the top point of the model

h_b/H	m	D(1) mm	D(2) mm	D(3) mm	D(4) mm	d (cm)	Dt mm
0.20	1 : 2	0.20	0.19	0.16	0.16	125	0.14
0.20	1 : 3	0.16	0.16	0.13	0.13	125	0.11
0.20	1 : 4	0.16	0.16	0.13	0.13	125	0.11
0.30	1 : 2	0.13	0.12	0.10	0.10	125	0.09
0.30	1 : 3	0.11	0.11	0.09	0.09	125	0.08
0.30	1 : 4	0.10	0.10	0.08	0.08	125	0.07
0.40	1 : 2	0.06	0.05	0.05	0.04	125	0.04
0.40	1 : 3	0.05	0.05	0.04	0.04	125	0.04
0.40	1 : 4	0.05	0.05	0.04	0.04	125	0.04

Table (7.2): Laboratory Results for Sand with Dr = 47% (φ =32°)

h_b/H	m	D(1) mm	D(2) mm	D(3) mm	D(4) mm	d (cm)	Dt mm
0.20	1 : 2	0.19	0.18	0.14	0.15	125	0.12
0.20	1 : 3	0.13	0.12	0.10	0.10	125	0.08
0.20	1 : 4	0.13	0.12	0.10	0.10	125	0.08
0.30	1 : 2	0.11	0.12	0.10	0.09	125	0.08
0.30	1 : 3	0.09	0.08	0.07	0.07	125	0.06
0.30	1 : 4	0.09	0.09	0.07	0.07	125	0.06
0.40	1 : 2	0.07	0.08	0.06	0.06	125	0.05
0.40	1 : 3	0.08	0.08	0.06	0.06	125	0.05
0.40	1 : 4	0.06	0.06	0.05	0.06	125	0.04

Table (7.3): Laboratory Results for Sand with Dr = 65% (φ =36°)

A finite element model for the sheet pile model is performed by the program. The model has 350 mm free height and 245mm driven depth. The deflections of the model for different berm heights and 1:2 berm slope are presented in Figures (7.8) to (7.10) for soil having 32 degree internal friction angle. Figures (7.11) to (7.13) presents the deflection for 34 degree angle of friction. Comparison the laboratory model and finite element results is made. Although The results from finite element analysis are less those from laboratory model, the difference is relatively small and accepted as shown in Table (7.4).

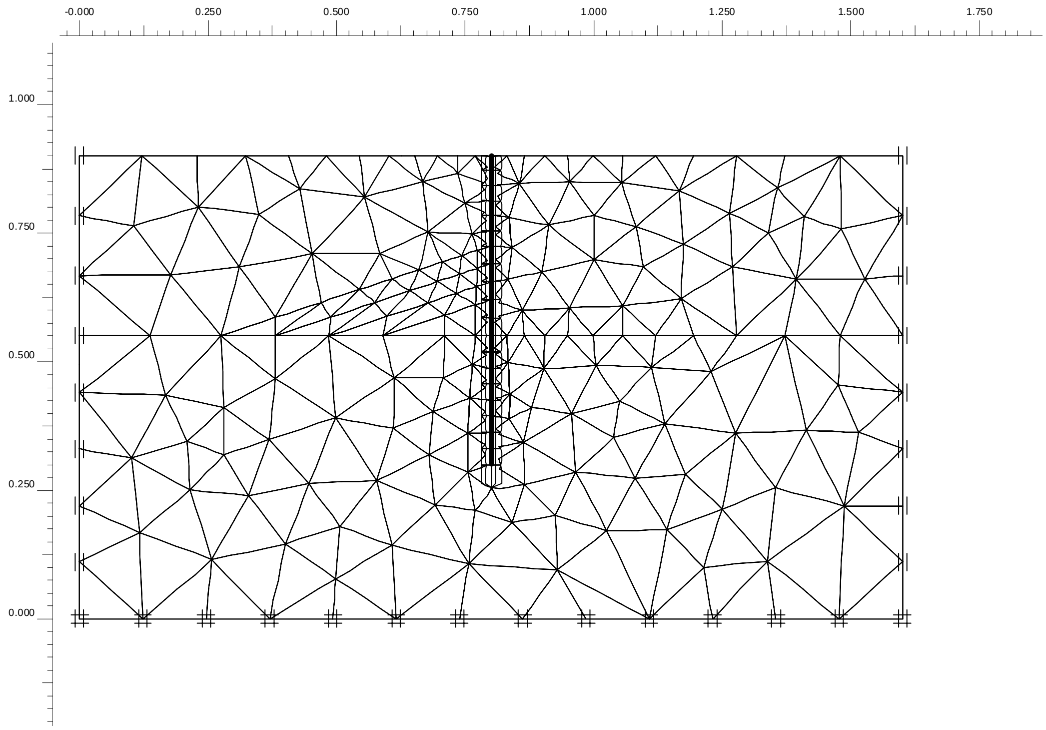


Figure (7.7): The Finite Element Mesh for the Laboratory Test

(h_b/Hw = 0.40,0.30,0.20, m=2)

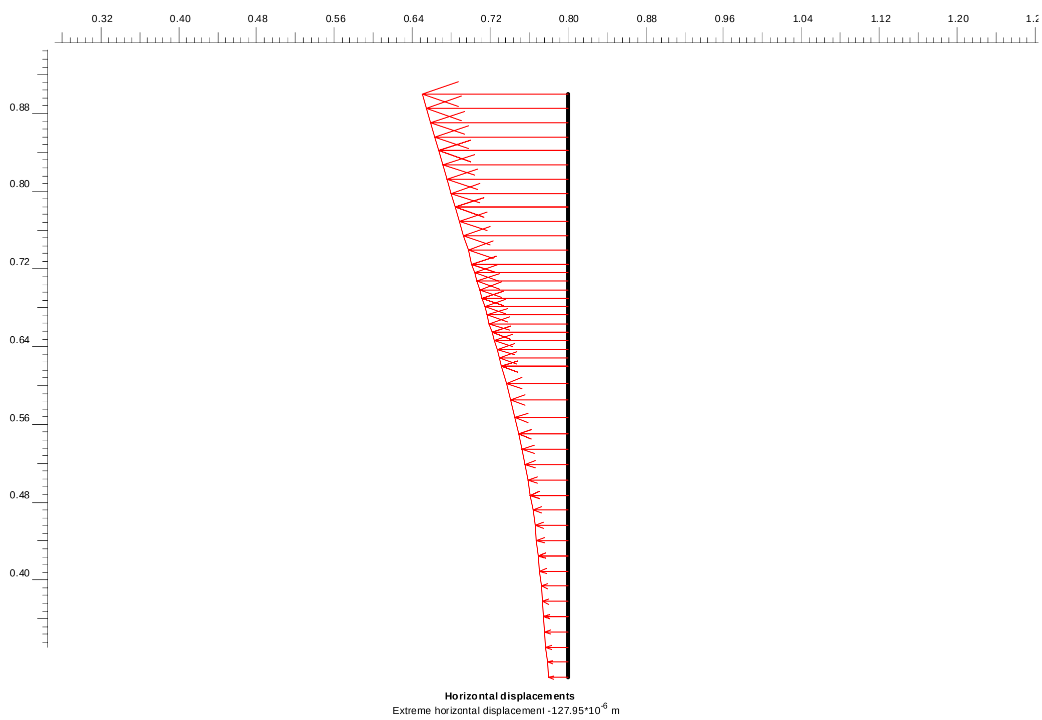


Figure (7.8): Deflection of the Model Sheet Pile from Finite Element (φ =32°, h_b/Hw =0.20, m=2)

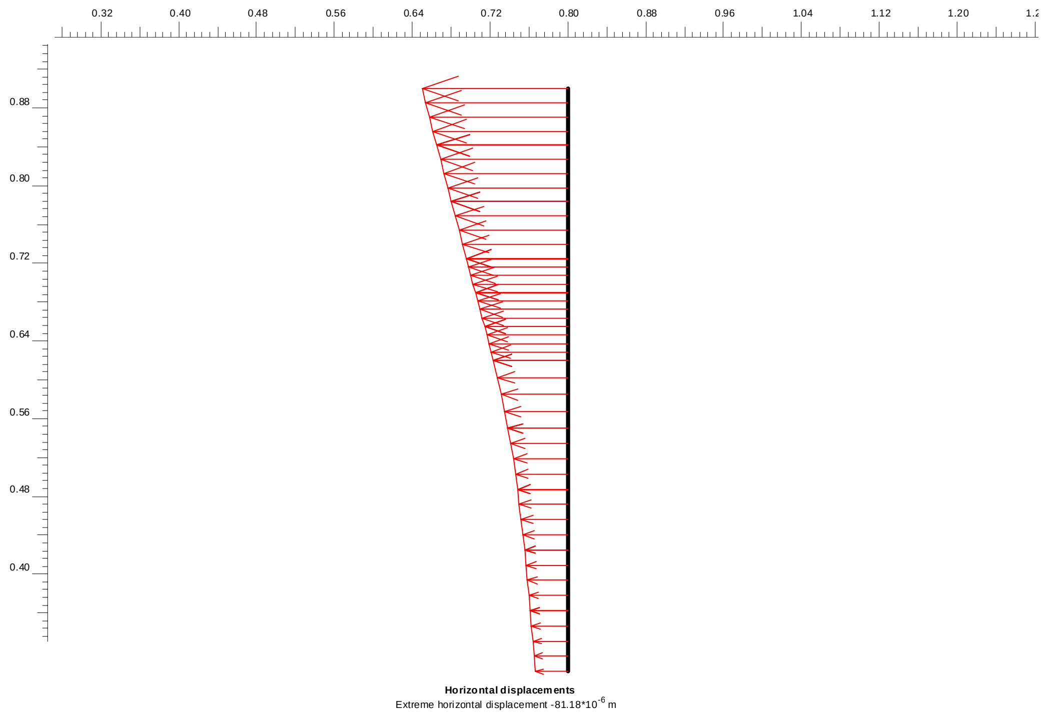


Figure (7.9): Deflection of the Model Sheet Pile from Finite Element

(φ =32°, h_b/Hw =0.30, m=2)

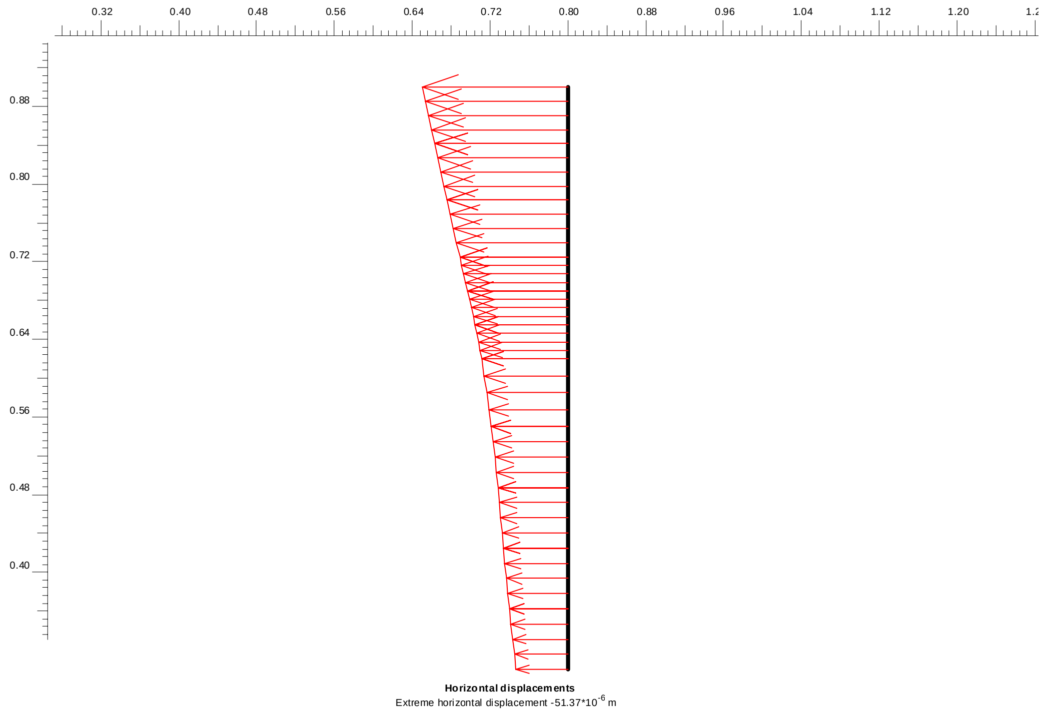


Figure (7.10): Deflection of the Model Sheet Pile from Finite Element
(φ =32°, h_b/Hw =0.40, m=2)

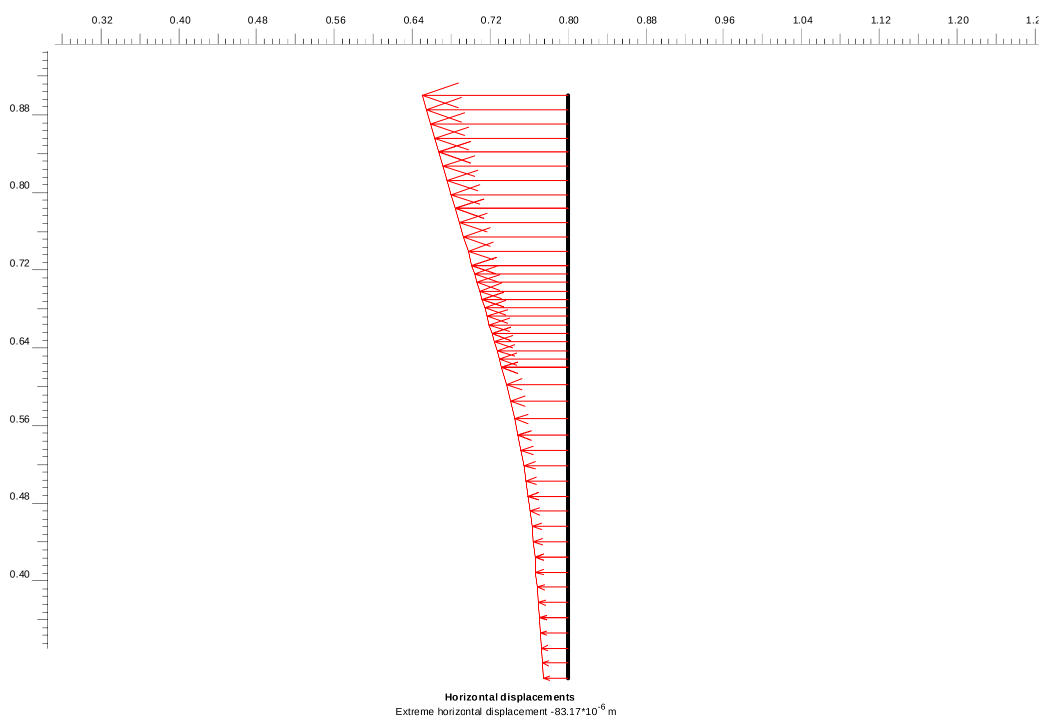


Figure (7.11): Deflection of the Model Sheet Pile from Finite Element
(φ =36°, h_b/Hw =0.20, m=2)

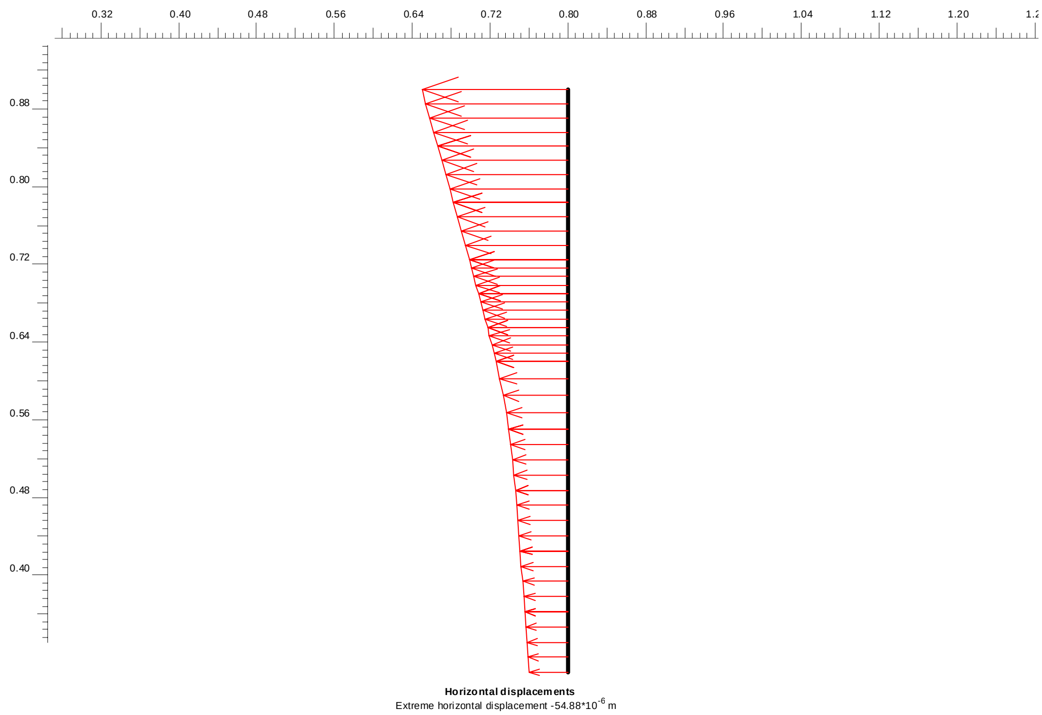


Figure (7.12): Deflection of the Model Sheet Pile from Finite Element
(φ =36°, h_b/Hw =0.30, m=2)

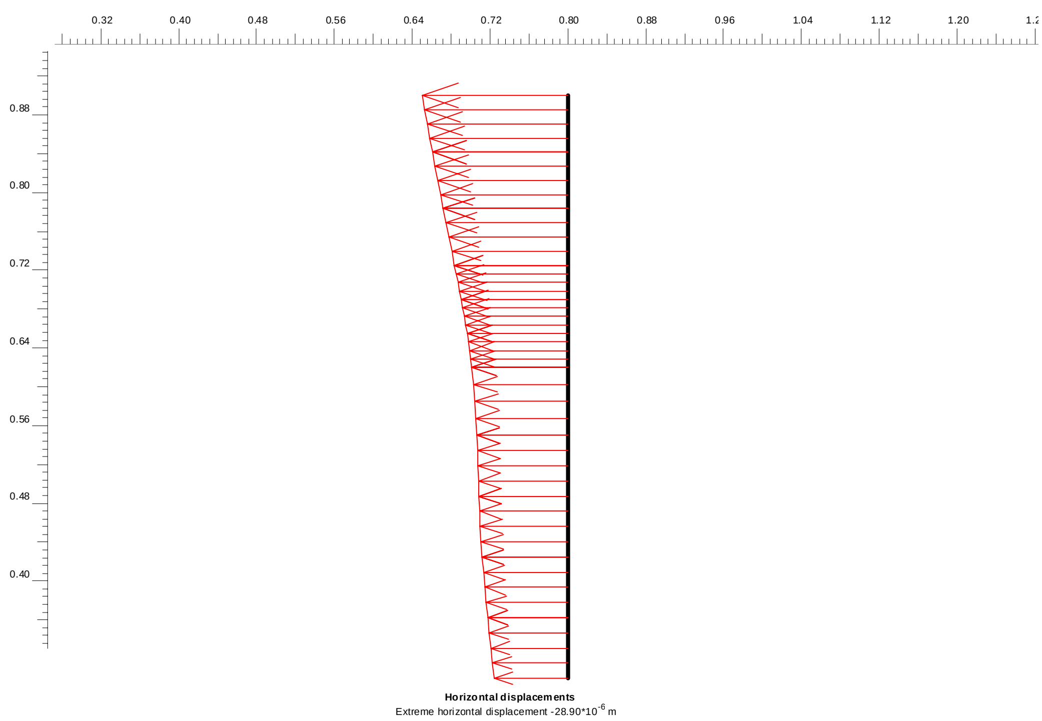


Figure (7.13): Deflection of the Model Sheet Pile from Finite Element
(φ =36°, h_b/Hw =0.40, m=2)

h_b/H	m	Deflection of Top Point (Angle of friction =32º)		Deflection of Top Point (Angle of friction =36º)	
		Finite Element	Laboratory	Finite Element	Laboratory
0.20	1 : 2	0.110	0.14	0.083	0.12
0.20	1 : 3	0.096	0.11	0.069	0.08
0.20	1 : 4	0.094	0.11	0.069	0.08
0.30	1 : 2	0.066	0.09	0.055	0.08
0.30	1 : 3	0.061	0.08	0.045	0.06
0.30	1 : 4	0.055	0.07	0.043	0.06
0.40	1 : 2	0.041	0.04	0.029	0.05
0.40	1 : 3	0.032	0.04	0.026	0.05
0.40	1 : 4	0.025	0.04	0.025	0.04

Table (7.4): Comparison between Finite Element and Laboratory Model Results

CHAPTER (8)

CONCLUSION AND RECOMMENDATIONS

It is common practice in the construction of wide excavations supported by a temporay wall to leave a slopping earth berm against the wall. It may be left in place throughtout the excavation, although it is often removed during the subsequent construction phases. The berm can play a critical role in the support system's performance. The berm offers a valuable means of minimizing the costs of the earth retaining structures. The temporary condition during construction is often worse than the permanent condition due to incomplete lateral support during construction. Berms can often be constructed at reasonable cost and can be removed either in short sections as permanent work proceeds or at the end of construction in one go. The use of berms has a vey economic effect when compared with other alternatives such as tie rods, anchors and struts

In the present work, the effect of the stablizing berm on the stability of the cantilever wall is estimated. In the past, researchers have tried to estimate the effect of the berm on the retaining structure. All these trails often depended on the limit equilibrium analyis theory. While limit equilibrium analyses for earth retaining structures, with or without berm, may yield estimates of internal forces in the wall, these methods can not reliably estimate wall displacements. This is because of these methods being based purely on statical computations with regard for wall stiffness properties. Furthmore, although beam theory may be utilized to estimate wall deflections, such procedures neglect the effect of soil stiffness and soil wall interaction effects. Most available methods are based on converting the berm into an increase in the driven depth or an increase in ground surface surchage on the passive side.

In this reaserch, the finite element analysis for a cantilever wall with stablizing berm is performed using a computer program called PLAXIS. The effect of change in the geomtery of the berm on the stablitiy and deformations of the wall have been investigated. The geometry of the berm is determined by different parameters including height, top width and slope. The finite element analysis is largerly effected by the properties of the soil and the retaining struture. A computer programes in Fortran 77 code are written to analysis the effect of berm and are presented in

Appendix (1). These programs are based on limit equilibrium and other approximate methods considering berm effect. One of these programs depends on the trial wedge. Comparisons are made between the finite element analysis and the different methods of limit analysis.

Laboratory work is performed to model the wall stablizing berm. The deflection of the cantilever wall model is measured using dail gauge. These deflections are compared with the results from a finite element model having the same dimensons.

The aim of the research is to calculate the effect of the berm on the stability of the cantilever wall. From the finite element analysis, the reduction factor of the moment on the wall is calculated. This factor can be obtained from the chart in Figure (5.1) for wall group No.(1) and zero top width of berm. Figure(5.3) presents the results for wall Group No. (2)

Also the deflection factor is estimated for the ratio between the deflection of wall without berm to the deflection of wall with stabilizing berm. The deflection of the cantilever wall is obtained from Figures (4.11) to (4.13)

The finite element analysis for the wall with stabilizing berm gives similar results to the trail wedge analysis. Finite element programs are easy to use provided that the user is an experienced engineer, and are useful as they provide deflections, stresses, and strains. Therefor, these are very useful in the design process. However, critical apraisal of program output is always required.

The results of the analysis prove that the first approximate method which converted the berm into an increase in driven depth over estimates values of moment on the wall. The correction for this method to reduce the overstimation may by performed using the factors presented in Table (6.25). The second approximate method that converts the berm into an increase in ground surface surcharge yields results that vary considerably when compared with those from finite element analyses. Factors to reduce moments of these analyses to values close to those of finite elements are given in Table (6.25).

The berm has a significant effect on the stability of the wall. The most important berms factor infleuncing stability is the berm height. This is reflected in this research in the berm to wall height ratio as defined in the thesis.This effect causes reduction in the maximum moment on the wall by about 50% when the ratio of berm to wall height is 0.60. The slope of berm has small effect on the stability especially when slope is more than 1: 4.

The written computer programs may be used for estimating the effect of berm on the maximum moment on the wall in an easy way. The results of bending moments may be used for the design of the earth retaining structure as a conservative design. Or the results of programs may be reduced using the suggested factors for the approximate methods of considering berm.

Recommendation for Future Research

The work described in this thesis is limited to cohesionless soil and cantilever walls. The study may eextensively extened to cover the following suggested points:

1. This analysis may be performed for walls with different driven depths.
2. The analysis may be performed for cohesive soils to simulate the effect of berm on the stability of cantilever wall.
3. The effect of berm on the behaviour of anchored walls may be performed to estimate the deformation of these walls in presence of the berm in cohesive and cohesionless soils.
4. The effect of stabilizing berm on decreasing the settlement of ground surface on the back of the retaining structures.
5. The economics of the stabilizing berm over the other methods of increasing stability such as anchors, rakers and struts, may be investigated.
6. The analysis may be performed using other soil models and comparing the results.
7. Laboratory work may be performed to measure the strains and stresses on the cantilever wall then estimating the bending moment on the wall from laboratory work and compared with the moment from the finite element analysis.
8. More analyses and laboratory work may be performed to investigate the distribution of the passive earth pressure on the embedement depth of cantilever walls with stabilizing berm and deduce equations for estimating the coefficient of passive earth pressure.

9. A comparison between the efficiency of different earth retaining structure support system, mechanically and economically, may be performed.

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APPENDIX (1)

Program Code (FORTRAN77)

Limit Equilibrium Analysis

Program No. (1)

```
C                     CANTILEVER SHEET PILE
C                     WITH STABLIZZING BERM
C               FIRST APPROXIMATE METHOD-USA METHOD
C             PREPARED  BY: Eng.YOUSSEF GOMAA YOUSSEF

C           **********************************************

      INTEGER m,I
      REAL PHI,G,h,he,Ka,Kp,Kpm,BB,BT,d,FS
      REAL ERR,ERR2,ERR1,Ab,AS,Ae,E1,E2,E3,M2,Mmax
      REAL P1,P2,P3,P4,F,m1,U,B,C
      REAL Ka1,Ka2,Ka3,Kp1,Kp2,Kp3,DELTA
      OPEN(1,FILE='BERMA2S',STATUS='NEW')
      WRITE (*,*)'ENTER ANGLE OF ITERNAL FRICTION='
      READ  (*,*) PHI
      WRITE (*,*)'ENTER UNIT WEIGHT OF SOIL      ='
      READ  (*,*) G
      WRITE (*,*)'ENTER FREE LENGTH OF SHEET PILE='
      READ  (*,*) h
      WRITE (*,*)'ENTER HEIGHT OF BERM           ='
      READ  (*,*) hb
      WRITE (*,*)'ENTER BOTTOM WIDTH OF BERM     ='
      READ  (*,*) BB
 2000 WRITE (*,*)'ENTER SLOPE OF BERM            ='
      READ  (*,*) m
      WRITE (1,*) 'INTPUT DATA OF THE ANALYSIS'
      WRITE (1,*)
      WRITE (1,2005) PHI
 2005 FORMAT(3X,'      ANGLE OF ITERNAL FRICTION     =' ,F7.2)
      WRITE (1,2010) G
 2010 FORMAT(3X,'      UNIT WEIGHT OF SOIL           =' ,F7.2)
      WRITE (1,2020) h
 2020 FORMAT(3X,'      FREE LENGTH OF SHEET PILE     =' ,F7.2)
      WRITE (1,2030) hb
 2030 FORMAT(3X,'      HEIGHT OF BERM                =' ,F7.2)
      WRITE (1,2040) BB
 2040 FORMAT(3X,'      BOTTOM WIDTH OF BERM          =' ,F7.2)
      WRITE (1,2050) m
 2050 FORMAT(3X,'      SLOPE OF BERM                 =' ,I4)
      PHI=PHI*22.0/(180*7)
      d=1.25*h
      DELTA=0.67*PHI
      Ka1=COS(DELTA)*(SIN(3.14/2-PHI))**2
      Ka2=SIN(DELTA+PHI)*SIN(PHI)/(SIN(3.14/2+DELTA)*SIN(3.14/2))
      Ka3=(SIN(3.14/2))**2*SIN(3.14/2+DELTA)
      Ka=Ka1/(Ka3*(1+Ka2**0.5)**2)
      Kp1=COS(DELTA)*(SIN(3.14/2+PHI))**2
      Kp2=SIN(DELTA+PHI)*SIN(PHI)/(SIN(3.14/2+DELTA)*SIN(3.14/2))
      Kp3=(SIN(3.14/2))**2*SIN(3.14/2+DELTA)
      Kp=Kp1/(Kp3*(1-Kp2**0.5)**2)
      WRITE (1,*)
      WRITE (1,*) 'OUTPUT DATA OF THE ANALYSIS'
      WRITE (1,*)
      WRITE (1,1001) Ka
 1001 FORMAT(8X,'Coeffcient of active earth pressure =' ,F7.2)
      WRITE (1,1002) Kp
```

```
1002 FORMAT(8X,'Coeffcient of passive earth pressure=' ,F7.2)
     BT=BB-m*hb
     Ab=(BT+BB)*hb/2
     q=Ab*G/(d*TAN(3.14/4+PHI/2))
     Kpm=Ka+0.001
3000 U=(G*h*Ka-q*Kpm)/(G*(Kpm-Ka))
     P1=G*h*Ka
     P1n=G*h*Ka-q*Kpm
     P2=(d-U)*G*(Kpm-Ka)
     P3=(h+d)*G*Kpm-d*G*Ka-q*Ka
     E1=P1*(h)/2+P1n*U/2
     E3=P2*(d-U)/2
     E2=E3-E1
     m1=2*E2/(P3+P2)
     ERR1=P1*(h/2)*(d+h/3)+P1n*U*(d-U/3)/2
     ERR2=(P3+P2)*(m1**2)/6-((d-U)**2)*P2/6
     ERR=ERR1+ERR2
     IF(ERR .LT. 0.10) THEN
     GO TO 4000
     ELSE
     Kpm=Kpm+0.0010
     GO TO 3000
     ENDIF
4000 FS=Kp/Kpm
     WRITE (1,1005) Kpm
1005 FORMAT(8X,'MOBOLIZED PASSIVE COEFFICIENT       =' ,F7.2)
     WRITE (1,1006) FS
1006 FORMAT(8X,'FACTOR OF SAFETY                    =' ,F7.2)
     WRITE (1,1007) U
1007 FORMAT(8X,'POINT OF ZERO EARTH PRESSURE        =' ,F7.2)
     WRITE (1,1008) m1
1008 FORMAT(8X,'HEIGHT OF POINT OF PASSIVE(m)       =' ,F7.2)
     X=(2*E1/(G*(Kpm-Ka)))**0.5
     IF((X+U).GT.(d-m1)) THEN
     P4=(d-m1-U)*(Kpm-Ka)*G/2
     F=P4*m1/(P3+P4)
     A=P4
     B=-2*F*P4
     C=2*F*E1-P4*F*(d-U-m1)
     X=(-B+(B**2-4*A*C)**0.5)/(2*A)
     M1=(P1*h/2)*(h/3+(d-m1)+X)+(P1*U/2)*(2*U/3+d-m1-U+X)
     M2=P4*(d-m1-U)/2*((d-m1-U)/3+X)+P4*(F-X)*X**3/(2*F)
     M3=(P4-X*(F-X)*P4/F)*X**2/3
     Mmax=M1-M2-M3
     ELSE
     M1=(P1*h/2)*(h/3+U+X)+(P1*U/2)*(2*U/3+X)
     M2=G*(Kpm-Ka)*(X**3)/6
     Mmax=M1-M2
     GO TO 5000
     ENDIF
5000 WRITE (1,1010) X
1010 FORMAT(8X,'POINT OF ZERO SHEAR                 =' ,F7.2)
     WRITE (1,1020) Mmax
1020 FORMAT(8X,'MAXIMUM MOMENT                      =' ,F7.2)
     STOP
     END
```

Program No. (2)

```
C                      CANTILEVER SHEET PILE
C                      WITH STABLIZZING BERM
C                FIRST APPROXIMATE METHOD-USA METHOD
C              PREPARED  BY: Eng.YOUSSEF GOMAA YOUSSEF

C            **********************************************
      INTEGER m,I
      REAL PHI,G,h,he,Ka,Kp,Kpm,BB,BT,d,FS
      REAL ERR,ERR2,ERR1,Ab,AS,Ae,E1,E2,E3,M2,Mmax
      REAL P1,P2,P3,P4,F,m1,U,B,C
      REAL Ka1,Ka2,Ka3,Kp1,Kp2,Kp3,DELTA
      OPEN(1,FILE='BERMA1S',STATUS='NEW')
      WRITE (*,*)'ENTER ANGLE OF ITERNAL FRICTION='
      READ  (*,*) PHI
      WRITE (*,*)'ENTER UNIT WEIGHT OF SOIL      ='
      READ  (*,*) G
      WRITE (*,*)'ENTER FREE LENGTH OF SHEET PILE='
      READ  (*,*) h
      WRITE (*,*)'ENTER HEIGHT OF BERM           ='
      READ  (*,*) hb
      WRITE (*,*)'ENTER BOTTOM WIDTH OF BERM     ='
      READ  (*,*) BB
 2000 WRITE (*,*)'ENTER SLOPE OF BERM(m<3)       ='
      READ  (*,*) m
      IF(m.GT.3)GO TO 2000
      WRITE (1,*) 'INTPUT DATA OF THE ANALYSIS'
      WRITE (1,*)
      WRITE (1,2005) PHI
 2005 FORMAT(3X,'      ANGLE OF ITERNAL FRICTION     =' ,F7.2)
      WRITE (1,2010) G
 2010 FORMAT(3X,'      UNIT WEIGHT OF SOIL           =' ,F7.2)
      WRITE (1,2020) h
 2020 FORMAT(3X,'      FREE LENGTH OF SHEET PILE     =' ,F7.2)
      WRITE (1,2030) hb
 2030 FORMAT(3X,'      HEIGHT OF BERM                =' ,F7.2)
      WRITE (1,2040) BB
 2040 FORMAT(3X,'      BOTTOM WIDTH OF BERM          =' ,F7.2)
      WRITE (1,2050) m
 2050 FORMAT(3X,'      SLOPE OF BERM                 =' ,I4)
      PHI=PHI*22.0/(180*7)
      d=1.25*h
      DELTA=0.67*PHI
      Ka1=COS(DELTA)*(SIN(3.14/2-PHI))**2
      Ka2=SIN(DELTA+PHI)*SIN(PHI)/(SIN(3.14/2+DELTA)*SIN(3.14/2))
      Ka3=(SIN(3.14/2))**2*SIN(3.14/2+DELTA)
      Ka=Ka1/(Ka3*(1+Ka2**0.5)**2)
      Kp1=COS(DELTA)*(SIN(3.14/2+PHI))**2
      Kp2=SIN(DELTA+PHI)*SIN(PHI)/(SIN(3.14/2+DELTA)*SIN(3.14/2))
      Kp3=(SIN(3.14/2))**2*SIN(3.14/2+DELTA)
      Kp=Kp1/(Kp3*(1-Kp2**0.5)**2)
```

```
      WRITE (1,*)
      WRITE (1,*) 'OUTPUT DATA OF THE ANALYSIS'
      WRITE (1,*)
      WRITE (1,1001) Ka
 1001 FORMAT(8X,'Coeffcient of active earth pressure =' ,F7.2)
      WRITE (1,1002) Kp
 1002 FORMAT(8X,'Coeffcient of passive earth pressure=' ,F7.2)
      he=BB/6
      h=h-he
      d=d+he
      BT=BB-m*hb
      Ab=(BT+BB)*hb/2
      Ae=BB*he/2
      As=Ab-Ae
      q=As*G/(d*TAN(3.14/4+PHI/2))
      Kpm=Ka+0.001
 3000 U=(G*h*Ka-q*Kpm)/(G*(Kpm-Ka))
      P1=G*h*Ka
      P1n=G*h*Ka-q*Kpm
      P2=(d-U)*G*(Kpm-Ka)
      P3=(h+d)*G*Kpm-d*G*Ka-q*Ka
      E1=P1*(h)/2+P1n*U/2
      E3=P2*(d-U)/2
      E2=E3-E1
      m1=2*E2/(P3+P2)
      ERR1=P1*(h/2)*(d+h/3)+P1n*U*(d-U/3)/2
      ERR2=(P3+P2)*(m1**2)/6-((d-U)**2)*P2/6
      ERR=ERR1+ERR2
      IF(ERR .LT. 0.10) THEN
      GO TO 4000
      ELSE
      Kpm=Kpm+0.0010
      GO TO 3000
      ENDIF
 4000 FS=Kp/Kpm
      WRITE (1,1005) Kpm
 1005 FORMAT(8X,'MOBOLIZED PASSIVE COEFFICIENT       =' ,F7.2)
      WRITE (1,1006) FS
 1006 FORMAT(8X,'FACTOR OF SAFETY                    =' ,F7.2)
      WRITE (1,1007) U
 1007 FORMAT(8X,'POINT OF ZERO EARTH PRESSURE        =' ,F7.2)
      WRITE (1,1008) m1
 1008 FORMAT(8X,'HEIGHT OF POINT OF PASSIVE(m)       =' ,F7.2)
      X=(2*E1/(G*(Kpm-Ka)))**0.5
      IF((X+U).GT.(d-m1)) THEN
      P4=(d-m1-U)*(Kpm-Ka)*G/2
      F=P4*m1/(P3+P4)
      A=P4
      B=-2*F*P4
      C=2*F*E1-P4*F*(d-U-m1)
      X=(-B+(B**2-4*A*C)**0.5)/(2*A)
      M1=(P1*h/2)*(h/3+(d-m1)+X)+(P1*U/2)*(2*U/3+d-m1-U+X)
      M2=P4*(d-m1-U)/2*((d-m1-U)/3+X)+P4*(F-X)*X**3/(2*F)
      M3=(P4-X*(F-X)*P4/F)*X**2/3
      Mmax=M1-M2-M3
      ELSE
      M1=(P1*h/2)*(h/3+U+X)+(P1*U/2)*(2*U/3+X)
      M2=G*(Kpm-Ka)*(X**3)/6
      Mmax=M1-M2
```

```
     GO TO 5000
     ENDIF
5000 WRITE (1,1010) X
1010 FORMAT(8X,'POINT OF ZERO SHEAR                  =' ,F7.2)
     WRITE (1,1020) Mmax
1020 FORMAT(8X,'MAXIMUM MOMENT                       =' ,F7.2)
     STOP
     END
```

Program No. (3)

```
                         C                     CANTILEVER SHEET PILE
C                     WITH STABLIZZING BERM
C               SECOND APPROXIMATE METHOD-UK METHOD
C             PREPARED  BY: Eng.YOUSSEF GOMAA YOUSSEF

C           **********************************************

      INTEGER m,I
      REAL PHI,G,h,Ka,Kp,Kpm,BB,BT,d,do,FS
      REAL A,B,C,Ab,E1,E2,M1,M2,Mmax
      REAL Ka1,Ka2,Ka3,Kp1,Kp2,Kp3,DELTA
      OPEN  (1,FILE='BERMA2U',STATUS='NEW')
      WRITE (1,*)'                    CANTILEVER SHEET PILE'
      WRITE (1,*)'                    WITH STABLIZZING BERM'
      WRITE (1,*)'             SECOND APPROXIMATE METHOD-UK METHOD'
      WRITE (1,*)'           PREPARED  BY: Eng.YOUSSEF GOMAA
YOUSSEF'
      WRITE (1,*)'
***************************************'
      WRITE (1,*)
      WRITE (*,*)'ENTER ANGLE OF ITERNAL FRICTION='
      READ  (*,*) PHI
      WRITE (*,*)'ENTER UNIT WEIGHT OF SOIL      ='
      READ  (*,*) G
      WRITE (*,*)'ENTER FREE LENGTH OF SHEET PILE='
      READ  (*,*) h
      WRITE (*,*)'ENTER HEIGHT OF BERM           ='
      READ  (*,*) hb
      WRITE (*,*)'ENTER BOTTOM WIDTH OF BERM     ='
      READ  (*,*) BB
      WRITE (*,*)'ENTER SLOPE OF BERM            ='
      READ  (*,*) m
      WRITE (1,*) 'INTPUT DATA OF THE ANALYSIS'
      WRITE (1,*)
      WRITE (1,2005) PHI
 2005 FORMAT(3X,'      ANGLE OF ITERNAL FRICTION=' ,F7.2)
      WRITE (1,2010) G
 2010 FORMAT(3X,'      UNIT WEIGHT OF SOIL      =' ,F7.2)
      WRITE (1,2020) h
 2020 FORMAT(3X,'      FREE LENGTH OF SHEET PILE=' ,F7.2)
      WRITE (1,2030) hb
 2030 FORMAT(3X,'      HEIGHT OF BERM           =' ,F7.2)
      WRITE (1,2040) BB
 2040 FORMAT(3X,'      BOTTOM WIDTH OF BERM     =' ,F7.2)
      WRITE (1,2050) m
 2050 FORMAT(3X,'      SLOPE OF BERM            =' ,I4)
      PHI=PHI*22.0/(180*7)
      DELTA=0.67*PHI
      d=1.25*h
      Ka1=COS(DELTA)*(SIN(3.14/2-PHI))**2
      Ka2=SIN(DELTA+PHI)*SIN(PHI)/(SIN(3.14/2+DELTA)*SIN(3.14/2))
      Ka3=(SIN(3.14/2))**2*SIN(3.14/2+DELTA)
      Ka=Ka1/(Ka3*(1+Ka2**0.5)**2)
      Kp1=COS(DELTA)*(SIN(3.14/2+PHI))**2
      Kp2=SIN(DELTA+PHI)*SIN(PHI)/(SIN(3.14/2+DELTA)*SIN(3.14/2))
      Kp3=(SIN(3.14/2))**2*SIN(3.14/2+DELTA)
```

```
      Kp=Kp1/(Kp3*(1-Kp2**0.5)**2)
      WRITE (1,*)
      WRITE (1,*) 'OUTPUT DATA OF THE ANALYSIS'
      WRITE (1,*)
      WRITE (1,1001) Ka
 1001 FORMAT(8X,'Coeffcient of active earth pressure (Ka) =' ,F7.2)
      WRITE (1,1002) Kp
 1002 FORMAT(8X,'Coeffcient of passive earth pressure (Kp)=' ,F7.2)
      BT=BB-m*hb
      Ab=(BT+BB)*hb/2
      q=Ab*G/(d*TAN(3.14/4+PHI/2))
      do=d/1.20
      E1=(h+do)**2*G*Ka/2
      Y1=(h+do)/3
      M1=E1*Y1
      Kpm=M1*2/(do**2*(q+do*G/3))
      FS=Kp/Kpm
      A=G*(Ka-Kpm)
      B=2*h*G*Ka-2*q*Kpm
      C=G*Ka*h**2
      X=(-B-(B**2-4*A*C)**0.50)/(2*A)
      Mmax=(h+X)**3*G*Ka/6-q*Kpm*X**2/2-Kpm*G*X**3/6
      WRITE (1,1005) Kpm
1005  FORMAT(8X,'MOBOLIZED PASSIVE COEFFICIENT              =' ,F7.2)
      WRITE (1,1006) FS
1006  FORMAT(8X,'FACTOR OF SAFETY                           =' ,F7.2)
      WRITE (1,1010) X
1010  FORMAT(8X,'POINT OF ZERO SHEAR                        =' ,F7.2)
      WRITE (1,1020) Mmax
1020  FORMAT(8X,'MAXIMUM MOMENT                             =' ,F7.2)
      STOP
      END
```

Program No. (4)

```
C                      CANTILEVER SHEET PILE
C                      WITH STABLIZZING BERM
C                FIRST APPROXIMATE METHOD-USA METHOD
C              PREPARED  BY: Eng.YOUSSEF GOMAA YOUSSEF

C           **********************************************

      INTEGER m,I
      REAL PHI,G,h,he,Ka,Kp,Kpm,BB,BT,d,FS
      REAL ERR,ERR2,ERR1,Ab,AS,Ae,E1,E2,E3,M2,Mmax
      REAL P1,P2,P3,P4,F,m1,U,B,C
      REAL Ka1,Ka2,Ka3,Kp1,Kp2,Kp3,DELTA
      OPEN(1,FILE='BERMA2S',STATUS='NEW')
      WRITE (*,*)'ENTER ANGLE OF ITERNAL FRICTION='
      READ  (*,*) PHI
      WRITE (*,*)'ENTER UNIT WEIGHT OF SOIL      ='
      READ  (*,*) G
      WRITE (*,*)'ENTER FREE LENGTH OF SHEET PILE='
      READ  (*,*) h
      WRITE (*,*)'ENTER HEIGHT OF BERM           ='
      READ  (*,*) hb
      WRITE (*,*)'ENTER BOTTOM WIDTH OF BERM     ='
      READ  (*,*) BB
 2000 WRITE (*,*)'ENTER SLOPE OF BERM            ='
      READ  (*,*) m
      WRITE (1,*) 'INTPUT DATA OF THE ANALYSIS'
      WRITE (1,*)
      WRITE (1,2005) PHI
 2005 FORMAT(3X,'      ANGLE OF ITERNAL FRICTION     =' ,F7.2)
      WRITE (1,2010) G
 2010 FORMAT(3X,'      UNIT WEIGHT OF SOIL           =' ,F7.2)
      WRITE (1,2020) h
 2020 FORMAT(3X,'      FREE LENGTH OF SHEET PILE     =' ,F7.2)
      WRITE (1,2030) hb
 2030 FORMAT(3X,'      HEIGHT OF BERM                =' ,F7.2)
      WRITE (1,2040) BB
 2040 FORMAT(3X,'      BOTTOM WIDTH OF BERM          =' ,F7.2)
      WRITE (1,2050) m
 2050 FORMAT(3X,'      SLOPE OF BERM                 =' ,I4)
      PHI=PHI*22.0/(180*7)
      d=1.25*h
      DELTA=0.67*PHI
      Ka1=COS(DELTA)*(SIN(3.14/2-PHI))**2
      Ka2=SIN(DELTA+PHI)*SIN(PHI)/(SIN(3.14/2+DELTA)*SIN(3.14/2))
      Ka3=(SIN(3.14/2))**2*SIN(3.14/2+DELTA)
      Ka=Ka1/(Ka3*(1+Ka2**0.5)**2)
      Kp1=COS(DELTA)*(SIN(3.14/2+PHI))**2
      Kp2=SIN(DELTA+PHI)*SIN(PHI)/(SIN(3.14/2+DELTA)*SIN(3.14/2))
      Kp3=(SIN(3.14/2))**2*SIN(3.14/2+DELTA)
      Kp=Kp1/(Kp3*(1-Kp2**0.5)**2)
      WRITE (1,*)
      WRITE (1,*) 'OUTPUT DATA OF THE ANALYSIS'
      WRITE (1,*)
      WRITE (1,1001) Ka
 1001 FORMAT(8X,'Coeffcient of active earth pressure =' ,F7.2)
      WRITE (1,1002) Kp
 1002 FORMAT(8X,'Coeffcient of passive earth pressure=' ,F7.2)
```

```
      BT=BB-m*hb
      Ab=(BT+BB)*hb/2
      q=Ab*G/(d*TAN(3.14/4+PHI/2))
      Kpm=Ka+0.001
 3000 U=(G*h*Ka-q*Kpm)/(G*(Kpm-Ka))
      P1=G*h*Ka
      P1n=G*h*Ka-q*Kpm
      P2=(d-U)*G*(Kpm-Ka)
      P3=(h+d)*G*Kpm-d*G*Ka-q*Ka
      E1=P1*(h)/2+P1n*U/2
      E3=P2*(d-U)/2
      E2=E3-E1
      m1=2*E2/(P3+P2)
      ERR1=P1*(h/2)*(d+h/3)+P1n*U*(d-U/3)/2
      ERR2=(P3+P2)*(m1**2)/6-((d-U)**2)*P2/6
      ERR=ERR1+ERR2
      IF(ERR .LT. 0.10) THEN
      GO TO 4000
      ELSE
      Kpm=Kpm+0.0010
      GO TO 3000
      ENDIF
 4000 FS=Kp/Kpm
      WRITE (1,1005) Kpm
 1005 FORMAT(8X,'MOBOLIZED PASSIVE COEFFICIENT       =' ,F7.2)
      WRITE (1,1006) FS
 1006 FORMAT(8X,'FACTOR OF SAFETY                    =' ,F7.2)
      WRITE (1,1007) U
 1007 FORMAT(8X,'POINT OF ZERO EARTH PRESSURE        =' ,F7.2)
      WRITE (1,1008) m1
 1008 FORMAT(8X,'HEIGHT OF POINT OF PASSIVE(m)       =' ,F7.2)
      X=(2*E1/(G*(Kpm-Ka)))**0.5
      IF((X+U).GT.(d-m1)) THEN
      P4=(d-m1-U)*(Kpm-Ka)*G/2
      F=P4*m1/(P3+P4)
      A=P4
      B=-2*F*P4
      C=2*F*E1-P4*F*(d-U-m1)
      X=(-B+(B**2-4*A*C)**0.5)/(2*A)
      M1=(P1*h/2)*(h/3+(d-m1)+X)+(P1*U/2)*(2*U/3+d-m1-U+X)
      M2=P4*(d-m1-U)/2*((d-m1-U)/3+X)+P4*(F-X)*X**3/(2*F)
      M3=(P4-X*(F-X)*P4/F)*X**2/3
      Mmax=M1-M2-M3
      ELSE
      M1=(P1*h/2)*(h/3+U+X)+(P1*U/2)*(2*U/3+X)
      M2=G*(Kpm-Ka)*(X**3)/6
      Mmax=M1-M2
      GO TO 5000
      ENDIF
 5000 WRITE (1,1010) X
 1010 FORMAT(8X,'POINT OF ZERO SHEAR                 =' ,F7.2)
      WRITE (1,1020) Mmax
 1020 FORMAT(8X,'MAXIMUM MOMENT                      =' ,F7.2)
      STOP
      END
```

Program No. (5)

```
C                   CANTILEVER SHEET PILE

C             WITH STABLIZZING BERM  (GRAPHICAL METHOD)

C              DIRECTED  BY: Eng.YOUSSEF GOMAA YOUSSEF

C            *********************************************

      INTEGER   I
      REAL SETA(100),SETAM
      REAL CO,PHI,G,h,he,Bb,Bt,d,A1,A2,X,Y,X2,X3,L
      REAL B1,B2,hb,SI,EM,Ka1,Ka2,Ka3,Ka,Kah,Kp,Kpm
      REAL P1,P2,P3,R1,R2,R3,MX,M,do
      REAL E(100),W(100),R(100),SETA1(100),SETA2(100)
      REAL E1,E2,E3,FS,F,A,B,C,MMAX
      OPEN(1,FILE='TRAILWU',STATUS='NEW')
      WRITE (1,*)'                     CANTILEVER SHEET PILE'
      WRITE (1,*)'                     WITH STABLIZZING BERM'
      WRITE (1,*)'              TRAIL WEDGE ANALYIS WITH UK METHOD'
      WRITE (1,*)'            PREPARED  BY: Eng.YOUSSEF GOMAA
YOUSSEF'
      WRITE (1,*)'
***************************************'
      WRITE (1,*)
      WRITE (*,*)'ENTER ANGLE OF ITERNAL FRICTION='
      READ  (*,*) PHI
      WRITE (*,*)'ENTER UNIT WEIGHT OF SOIL      ='
      READ  (*,*) G
      WRITE (*,*)'ENTER FREE LENGTH OF SHEET PILE='
      READ  (*,*) h
      WRITE (*,*)'ENTER TOP WIDTH OF BERM          ='
      READ  (*,*) BT
      WRITE (*,*)'ENTER HEIGHT OF BERM             ='
      READ  (*,*) Hb
      WRITE (*,*)'ENTER SLOPE ANGLE OF BERM        ='
      READ  (*,*) ETA
      WRITE (*,*)'ENTER DRIVEN DEPTH OF SHEET PILE  ='
      READ  (*,*) d
      WRITE (*,*)'ENTER ANGLE OF FRICTION WALL&SOIL ='
      READ  (*,*) SI
      WRITE (1,*) 'INTPUT DATA OF THE ANALYSIS'
      WRITE (1,*)
      WRITE (1,2005) PHI
 2005 FORMAT(3X,'     ANGLE OF ITERNAL FRICTION     =' ,F7.2)
      WRITE (1,2010) G
 2010 FORMAT(3X,'     UNIT WEIGHT OF SOIL           =' ,F7.2)
      WRITE (1,2020) h
 2020 FORMAT(3X,'     FREE LENGTH OF SHEET PILE     =' ,F7.2)
      WRITE (1,2030) hb
 2030 FORMAT(3X,'     HEIGHT OF BERM                =' ,F7.2)
      WRITE (1,2040) BT
 2040 FORMAT(3X,'     TOP WIDTH OF BERM             =' ,F7.2)
      WRITE (1,2050) ETA
 2050 FORMAT(3X,'     SLOPE ANGLE OF BERM           =' ,F7.2)
      WRITE (1,2060) SI
 2060 FORMAT(3X,'     ANGLE OF FRICTION WITH WALL   =' ,F7.2)
      Bb=BT+Hb/TAN(3.14*ETA/180)
```

```
      PHI=PHI*3.14/180
      SI=SI*3.14/180
      SETA(0)=0
      DO 1000 I=0,89,1
      SETA(I+1)=SETA(I)+1
      SETA1(I+1)=SETA(I+1)*3.14/180
      X1=(d+hb)*TAN(SETA1(I+1))
      IF (X1.LE.Bt) THEN
      W(I+1)=G*(hb+d)*X1/2
      ELSE
      X2=d*TAN(SETA1(I+1))
      IF (X2.LE.Bb) THEN
      ETA1=ETA*3.14/180
      L=(Bb-X2)*SIN(1.57-SETA1(I+1))/SIN(1.57-ETA1+SETA1(I+1))
      Y=L*SIN(ETA1)
      X3=(Y+d)*TAN(SETA1(I+1))
      W(I+1)=(X3*(Y+d)/2+(X3+Bt)/2*(Hb-Y))*G
      ELSE
      W(I+1)=(X2*d/2+(Bt+Bb)*Hb/2)*G
      ENDIF
      ENDIF
      SETA2(I+1)=3.14/2-SETA1(I+1)
      C1=SIN(PHI+SETA2(I+1))
      C2=COS(SI+PHI+SETA2(I+1))
      E(I+1)=C1*W(I+1)/C2
 1000 CONTINUE
      EM=10000.00
      DO 2000 I=45,89,1
      IF(E(I).LT.0.001) THEN
      GO TO 2000
      ENDIF
      IF(E(I) .LT. EM) THEN
      EM=E(I)
      SETAM=SETA(I)
      ENDIF
 2000 CONTINUE
      WRITE (1,*) 'OUTPUT DATA OF THE ANALYSIS'
      WRITE (1,*)
      WRITE(1,2070)EM
 2070 FORMAT(8X,'PASSIVE EARTH PRESSURE FORCE        =' ,F7.2)
      WRITE(1,2080)SETAM
 2080 FORMAT(8X,'INCLINATION OF FAILURE PLAN         =' ,F7.2)
      Ka1=COS(SI)*(SIN(3.14/2-PHI))**2
      Ka2=SIN(SI+PHI)*SIN(PHI)/(SIN(3.14/2+SI)*SIN(3.14/2))
      Ka3=(SIN(3.14/2))**2*SIN(3.14/2+SI)
      Ka=Ka1/(Ka3*(1+Ka2**0.5)**2)
      Kp=EM*2/(G*(d+Hb)**2)
      Kp=Kp*COS(SI)
      WRITE (1,1001) Ka
 1001 FORMAT(8X,'Coeffcient of active earth pressure =',F7.2)
      WRITE (1,1002) Kp
 1002 FORMAT(8X,'Coeffcient of passive earth pressure=',F7.2)
      d=d+hb
      h=h-hb
      do=d/1.20
      E1=(h+do)**2*G*Ka/2
      Y1=(h+do)/3
      MX=E1*Y1
      Kpm=MX*2/(do**2*(do*G/3))
```

```
      FS=Kp/Kpm
      A=G*(Ka-Kpm)
      B=2*h*G*Ka
      C=G*Ka*h**2
      X=(-B-(B**2-4*A*C)**0.50)/(2*A)
      Mmax=(h+X)**3*G*Ka/6-Kpm*G*X**3/6
      WRITE (1,1005) Kpm
1005  FORMAT(8X,'MOBOLIZED PASSIVE COEFFICIENT           =' ,F7.2)
      WRITE (1,1006) FS
1006  FORMAT(8X,'FACTOR OF SAFETY                        =' ,F7.2)
      WRITE (1,1010) X
1010  FORMAT(8X,'POINT OF ZERO SHEAR                     =' ,F7.2)
      WRITE (1,1020) Mmax
1020  FORMAT(8X,'MAXIMUM MOMENT                          =' ,F7.2)
      STOP
      END
```

Program No. (6)

```
C                   CANTILEVER SHEET PILE

C             WITH STABLIZZING BERM  (GRAPHICAL METHOD)



C              DIRECTED  BY: Eng.YOUSSEF GOMAA YOUSSEF



C            **********************************************

      INTEGER   I
      REAL SETA(100),SETAM
      REAL CO,PHI,G,h,he,Bb,Bt,d,A1,A2,X,Y,X2,X3,L
      REAL B1,B2,hb,SI,EM,Ka1,Ka2,Ka3,Ka,Kah,Kp,Kpm
      REAL P1,P2,P3,R1,R2,R3,MX,M,m1,M2,M3,U,ERR,ERR1,ERR2
      REAL E(100),W(100),R(100),SETA1(100),SETA2(100)
      REAL E1,E2,E3,P1n,FS,F,A,B,C,P4,MMAX
      OPEN(1,FILE='TRAILWS',STATUS='NEW')
      WRITE (1,*)'                     CANTILEVER SHEET PILE'
      WRITE (1,*)'                     WITH STABLIZZING BERM'
      WRITE (1,*)'              TRAIL WEDGE ANALYIS WITH UK METHOD'
      WRITE (1,*)'            PREPARED  BY: Eng.YOUSSEF GOMAA
YOUSSEF'
      WRITE (1,*)'
****************************************'
      WRITE (1,*)
      WRITE (*,*)'ENTER ANGLE OF ITERNAL FRICTION='
      READ  (*,*) PHI
      WRITE (*,*)'ENTER UNIT WEIGHT OF SOIL      ='
      READ  (*,*) G
      WRITE (*,*)'ENTER FREE LENGTH OF SHEET PILE='
      READ  (*,*) h
      WRITE (*,*)'ENTER TOP WIDTH OF BERM          ='
      READ  (*,*) BT
      WRITE (*,*)'ENTER HEIGHT OF BERM             ='
      READ  (*,*) Hb
      WRITE (*,*)'ENTER SLOPE ANGLE OF BERM        ='
      READ  (*,*) ETA
      WRITE (*,*)'ENTER DRIVEN DEPTH OF SHEET PILE  ='
      READ  (*,*) d
      WRITE (*,*)'ENTER ANGLE OF FRICTION WALL&SOIL ='
      READ  (*,*) SI
      WRITE (1,*) 'INTPUT DATA OF THE ANALYSIS'
      WRITE (1,*)
      WRITE (1,2005) PHI
 2005 FORMAT(3X,'     ANGLE OF ITERNAL FRICTION     =' ,F7.2)
      WRITE (1,2010) G
 2010 FORMAT(3X,'     UNIT WEIGHT OF SOIL           =' ,F7.2)
      WRITE (1,2020) h
 2020 FORMAT(3X,'     FREE LENGTH OF SHEET PILE     =' ,F7.2)
      WRITE (1,2030) hb
 2030 FORMAT(3X,'     HEIGHT OF BERM                =' ,F7.2)
      WRITE (1,2040) BT
 2040 FORMAT(3X,'     TOP WIDTH OF BERM             =' ,F7.2)
      WRITE (1,2050) ETA
```

```
2050 FORMAT(3X,'      SLOPE ANGLE OF BERM            =' ,F7.2)
     WRITE (1,2060) SI
2060 FORMAT(3X,'      ANGLE OF FRICTION WITH WALL    =' ,F7.2)
     Bb=BT+Hb/TAN(3.14*ETA/180)
     PHI=PHI*3.14/180
     SI=SI*3.14/180
     SETA(0)=0
     DO 1000 I=0,89,1
     SETA(I+1)=SETA(I)+1
     SETA1(I+1)=SETA(I+1)*3.14/180
     X1=(d+hb)*TAN(SETA1(I+1))
     IF (X1.LE.Bt) THEN
     W(I+1)=G*(hb+d)*X1/2
     ELSE
     X2=d*TAN(SETA1(I+1))
     IF (X2.LE.Bb) THEN
     ETA1=ETA*3.14/180
     L=(Bb-X2)*SIN(1.57-SETA1(I+1))/SIN(1.57-ETA1+SETA1(I+1))
     Y=L*SIN(ETA1)
     X3=(Y+d)*TAN(SETA1(I+1))
     W(I+1)=(X3*(Y+d)/2+(X3+Bt)/2*(Hb-Y))*G
     ELSE
     W(I+1)=(X2*d/2+(Bt+Bb)*Hb/2)*G
     ENDIF
     ENDIF
     SETA2(I+1)=3.14/2-SETA1(I+1)
     C1=SIN(PHI+SETA2(I+1))
     C2=COS(SI+PHI+SETA2(I+1))
     E(I+1)=C1*W(I+1)/C2
1000 CONTINUE
     EM=10000.00
     DO 2000 I=45,89,1
     IF(E(I).LT.0.001) THEN
     GO TO 2000
     ENDIF
     IF(E(I) .LT. EM) THEN
     EM=E(I)
     SETAM=SETA(I)
     ENDIF
2000 CONTINUE
     WRITE (1,*) 'OUTPUT DATA OF THE ANALYSIS'
     WRITE (1,*)
     WRITE(1,2070)EM
2070 FORMAT(8X,'PASSIVE EARTH PRESSURE FORCE         =' ,F7.2)
     WRITE(1,2080)SETAM
2080 FORMAT(8X,'INCLINATION OF FAILURE PLAN          =' ,F7.2)
     Ka1=COS(SI)*(SIN(3.14/2-PHI))**2
     Ka2=SIN(SI+PHI)*SIN(PHI)/(SIN(3.14/2+SI)*SIN(3.14/2))
     Ka3=(SIN(3.14/2))**2*SIN(3.14/2+SI)
     Ka=Ka1/(Ka3*(1+Ka2**0.5)**2)
     Kp=EM*2/(G*(d+Hb)**2)
     Kp=Kp*COS(SI)
     WRITE (1,1001) Ka
1001 FORMAT(8X,'Coeffcient of active earth pressure =',F7.2)
     WRITE (1,1002) Kp
1002 FORMAT(8X,'Coeffcient of passive earth pressure=',F7.2)
     Kpm=Ka+0.001
     h=h-hb
     d=d+hb
```

```
3000 U=(G*h*Ka)/(G*(Kpm-Ka))
     P1=G*h*Ka
     P1n=G*h*Ka
     P2=(d-U)*G*(Kpm-Ka)
     P3=(h+d)*G*Kpm-d*G*Ka
     E1=P1*(h)/2+P1n*U/2
     E3=P2*(d-U)/2
     E2=E3-E1
     m1=2*E2/(P3+P2)
     ERR1=P1*(h/2)*(d+h/3)+P1n*U*(d-U/3)/2
     ERR2=(P3+P2)*(m1**2)/6-((d-U)**2)*P2/6
     ERR=ERR1+ERR2
     IF(ERR .LT. 0.0010) THEN
     GO TO 4000
     ELSE
     Kpm=Kpm+0.10
     GO TO 3000
     ENDIF
4000 FS=Kp/Kpm
     WRITE (1,1005) Kpm
1005 FORMAT(8X,'MOBOLIZED PASSIVE COEFFICIENT       =' ,F7.2)
     WRITE (1,1006) FS
1006 FORMAT(8X,'FACTOR OF SAFETY                    =' ,F7.2)
     WRITE (1,1007) U
1007 FORMAT(8X,'POINT OF ZERO EARTH PRESSURE        =' ,F7.2)
     WRITE (1,1008) m1
1008 FORMAT(8X,'HEIGHT OF POINT OF PASSIVE(m)       =' ,F7.2)
     X=(2*E1/(G*(Kpm-Ka)))**0.5
     IF((X+U).GT.(d-m1)) THEN
     P4=(d-m1-U)*(Kpm-Ka)*G/2
     F=P4*m1/(P3+P4)
     A=P4
     B=-2*F*P4
     C=2*F*E1-P4*F*(d-U-m1)
     X=(-B+(B**2-4*A*C)**0.5)/(2*A)
     MX=(P1*h/2)*(h/3+(d-m1)+X)+(P1*U/2)*(2*U/3+d-m1-U+X)
     M2=P4*(d-m1-U)/2*((d-m1-U)/3+X)+P4*(F-X)*X**3/(2*F)
     M3=(P4-X*(F-X)*P4/F)*X**2/3
     Mmax=MX-M2-M3
     ELSE
     MX=(P1*h/2)*(h/3+U+X)+(P1*U/2)*(2*U/3+X)
     M2=G*(Kpm-Ka)*(X**3)/6
     Mmax=MX-M2
     GO TO 5000
     ENDIF
5000 WRITE (1,1010) X
1010 FORMAT(8X,'POINT OF ZERO SHEAR                 =' ,F7.2)
     WRITE (1,1020) Mmax
1020 FORMAT(8X,'MAXIMUM MOMENT                      =' ,F7.2)
     STOP
     END
```

APPENDIX (2)

RESULTS OF SOIL GROUP (2)

(φ=30°)

1. Numerical Results from Finite Element Analysis

1.1. Effect of Varying Driven Depth of the Wall

Increase in Driven depth (m)	Wall Group(1)		Wall Group(2)	
	Moment (KN.m/m')	Deflection (mm)	Moment (KN.m/m')	Deflection (mm)
0.00	49.71	14.01	52.69	17.12
0.20	43.33	9.75	50.48	14.08
0.40	39.79	7.39	45.68	10.13
0.60	35.24	5.43	42.19	7.73
0.80	31.04	3.97	38.51	6.15
1.00	26.58	2.81	34.37	4.45
1.20	21.97	1.86	30.41	3.48
1.40	18.84	1.18	26.15	2.47
1.60	14.88	0.62	22.43	1.77

Table (A2.1): Bending Moment and Deflection
3.0m Initial Free Height Wall

Increase in Driven depth (m)	Wall Group(1)		Wall Group(2)	
	Moment (KN.m/m')	Deflection (mm)	Moment (KN.m/m')	Deflection (mm)
0.00	213.09	34.46	209.48	27.91
0.20	181.00	25.84	199.19	23.88
0.40	165.28	21.76	183.61	19.97
0.60	159.16	19.30	167.99	16.64
0.80	132.93	15.06	152.39	13.86
1.00	113.37	11.91	141.59	11.99
1.20	100.92	9.90	127.80	10.06
1.40	92.68	8.66	109.85	7.79
1.60	82.00	7.22	102.26	6.82
1.80	73.78	6.15	90.53	5.48
2.00	64.32	5.05	80.17	4.44
2.20	55.59	4.09	66.30	3.36
2.40	44.79	3.04	58.60	2.71

Table (A2.2): Bending Moment and Deflection
5.0m Initial Free Height Wall

Increase in Driven depth (m)	Wall Group(1)		Wall Group(2)	
	Moment (KN.m/m')	Deflection (mm)	Moment (KN.m/m')	Deflection (mm)
0.00	501.65	85.26	547.72	60.27
0.20	465.16	75.32	501.55	51.45
0.40	439.89	68.74	462.00	45.02
0.60	391.95	58.81	428.61	39.52
0.80	363.85	52.81	403.94	35.60
1.00	331.78	46.17	368.05	30.92
1.20	302.61	40.60	344.05	27.71
1.40	272.97	35.19	306.48	23.53
1.60	253.56	31.55	288.29	21.27
1.80	229.60	27.48	259.52	18.42
2.00	207.91	24.07	237.81	16.20
2.20	182.43	20.07	214.63	14.10
2.40	168.37	17.80	194.64	12.26
2.60	150.56	15.28	172.29	10.40
2.80	133.94	13.00	154.45	8.96

Table (A2.3): Bending Moment and Deflection
7.0m Initial Free Height Wall

1.2. Results of Wall with Stabilizing Berm

1.2.1. Results of Wall with Zero Top Berm Width

Berm Height (m)	Berm Slope VL. To HL.	Wall group No.(1)		Wall group No.(2)	
		Moment (KN.m/m')	Deflection (mm)	Moment (KN.m/m')	Deflection (mm)
0.60	1 : 2	41.77	12.09	48.89	15.00
0.60	1 : 3	40.90	10.14	46.25	12.96
0.60	1 : 4	36.79	7.85	44.07	11.81
0.90	1 : 2	37.02	9.83	43.80	12.53
0.90	1 : 3	34.38	7.35	40.55	10.13
0.90	1 : 4	30.96	5.38	38.99	8.75
1.20	1 : 2	30.94	7.11	38.10	9.45
1.20	1 : 3	27.35	4.57	35.45	7.38
1.20	1 : 4	24.91	3.09	33.33	5.80
1.50	1 : 2	25.10	4.66	33.12	7.07
1.50	1 : 3	20.43	2.20	29.25	4.59
1.50	1 : 4	19.32	1.30	27.64	3.29
1.80	1 : 2	19.87	2.63	27.45	4.32
1.80	1 : 3	16.50	1.00	23.91	2.65
1.80	1 : 4	16.00	0.64	22.52	1.49

Table (A2.4): Bending Moment and Deflection
3.0m Free Height Wall

Berm Height (m)	Berm Slope VL. To HL.	Wall group No.(1)		Wall group No.(2)	
		Moment (KN.m/m’)	Deflection (mm)	Moment (KN.m/m’)	Deflection (mm)
1.00	1 : 2	167.10	25.07	183.87	23.23
1.00	1 : 3	155.01	22.65	170.45	21.05
1.00	1 : 4	145.85	20.73	160.50	18.75
1.20	1 : 2	137.69	19.57	155.89	18.57
1.20	1 : 3	119.75	16.17	136.85	15.37
1.20	1 : 4	103.77	12.84	126.47	13.10
1.50	1 : 2	108.16	14.45	128.17	14.25
1.50	1 : 3	82.56	9.67	101.55	10.00
1.50	1 : 4	74.95	7.64	92.76	7.82
1.50	1 : 2	76.27	9.26	97.13	9.85
1.50	1 : 3	55.12	5.24	73.14	5.87
1.50	1 : 4	51.06	3.94	66.56	4.05
1.80	1 : 2	51.92	5.57	72.53	6.57
1.80	1 : 3	36.60	2.49	49.76	2.53
1.80	1 : 4	33.37	2.50	44.54	1.53

Table (A2.5): Bending Moment and Deflection
5.0m Free Height Wall

Berm Height (m)	Berm Slope VL. To HL.	Wall group No.(1)		Wall group No.(2)	
		Moment (KN.m/m’)	Deflection (mm)	Moment (KN.m/m’)	Deflection (mm)
1.40	1 : 2	410.83	69.68	440.00	49.01
1.40	1 : 3	381.25	63.81	407.54	44.73
1.40	1 : 4	351.43	55.55	396.37	40.26
2.10	1 : 2	320.05	51.70	364.84	39.05
2.10	1 : 3	264.34	41.04	364.84	32.25
2.10	1 : 4	237.20	34.37	277.67	25.49
2.80	1 : 2	234.61	36.63	265.22	26.50
2.80	1 : 3	179.34	25.69	208.35	19.04
2.80	1 : 4	164.47	20.80	189.27	14.75
3.50	1 : 2	163.78	24.37	194.96	18.56
3.50	1 : 3	119.32	14.80	139.19	10.81
3.50	1 : 4	103.55	10.35	125.85	7.81
4.20	1 : 2	106.07	14.76	126.37	10.75
4.20	1 : 3	69.71	6.22	87.84	5.03
4.20	1 : 4	64.68	4.19	81.08	3.25

Table (A2.6): Bending Moment and Deflection
7.0m Free Height Wall

1.2.2. Results of Wall with Different Top Berm Widths

Berm height (m)	Berm slope VL. To HL.	Moment (KN.m/m')			Deflection (mm)		
		Bt=1.0	**Bt=1.5**	**Bt=3.0**	**Bt=1.0**	**Bt=1.5**	**Bt=3.0**
0.60	1 : 2	35.50	35.73	33.32	7.91	7.69	5.340
0.60	1 : 3	35.21	34.05	33.45	7.60	6.54	5.140
0.60	1 : 4	33.41	33.88	33.59	6.23	6.21	5.120
0.90	1 : 2	29.93	28.03	27.84	5.59	4.66	3.110
0.90	1 : 3	28.25	27.55	28.06	4.72	3.89	2.910
0.90	1 : 4	27.65	28.01	28.57	3.81	3.52	2.840
1.20	1 : 2	23.87	22.45	22.14	3.58	2.65	1.460
1.20	1 : 3	22.56	21.91	22.43	2.51	1.89	1.270
1.20	1 : 4	22.24	21.93	22.69	1.82	1.56	1.190
1.50	1 : 2	18.90	16.78	17.84	1.90	1.19	0.303
1.50	1 : 3	17.35	16.81	18.20	0.90	0.67	0.163
1.50	1 : 4	17.08	17.19	17.37	0.64	0.40	0.0
1.80	1 : 2	14.08	12.98	13.47	0.65	0.05	0.0
1.80	1 : 3	13.72	13.13	13.93	0.35	0.0	0.0
1.80	1 : 4	13.50	13.36	13.41	0.10	0.00	0.0

Table (A2.7): Bending Moment and Deflection
3.0m Free Height Wall

Berm height (m)	Berm slope VL. To HL.	Moment (KN.m/m')			Deflection (mm)		
		Bt=1.0	**Bt=1.5**	**Bt=3.0**	**Bt=1.0**	**Bt=1.5**	**Bt=3.0**
1.00	1 : 2	149.3	126.6	114.0	21.86	17.37	14.16
1.00	1 : 3	142.3	122.0	112.4	20.43	16.00	13.42
1.00	1 : 4	135.3	117.9	113.6	18.55	14.99	13.26
1.50	1 : 2	119.0	98.26	83.32	16.35	12.64	9.020
1.50	1 : 3	95.48	89.31	82.87	11.78	10.46	8.140
1.50	1 : 4	89.83	86.60	83.48	10.16	9.26	7.810
2.00	1 : 2	84.79	68.30	57.23	10.61	7.84	5.500
2.00	1 : 3	65.79	62.09	58.42	6.68	6.03	4.640
2.00	1 : 4	63.37	61.76	60.27	5.78	5.38	4.440
2.50	1 : 2	52.56	46.98	39.05	5.50	4.73	2.710
2.50	1 : 3	43.96	41.77	41.73	3.35	3.08	1.997
2.50	1 : 4	43.58	41.94	42.43	2.79	2.47	1.926
3.00	1 : 2	208.1	29.04	26.13	3.12	2.16	0.721
3.00	1 : 3	208.1	27.58	28.53	33.81	0.81	0.391
3.00	1 : 4	208.1	27.76	29.56	33.81	0.67	0.390

Table (A2.8): Bending Moment and Deflection
5.0m Free Height Wall

Berm height (m)	Berm slope VL. To HL.	Moment (KN.m/m’)			Deflection (mm)		
		Bt=1.0	**Bt=1.5**	**Bt=3.0**	**Bt=1.0**	**Bt=1.5**	**Bt=3.0**
1.40	1 : 2	376.3	352.7	295.8	62.48	58.17	46.01
1.40	1 : 3	341.9	328.1	289.0	59.58	53.19	44.02
1.40	1 : 4	323.3	301.1	293.5	50.76	45.94	42.72
2.10	1 : 2	284.4	272.7	214.9	45.75	43.18	31.69
2.10	1 : 3	232.6	231.6	199.9	37.01	34.56	26.78
2.10	1 : 4	228.7	222’.6	194.3	32.57	30.80	24.45
2.80	1 : 2	200.4	169.8	143.8	30.73	25.27	19.52
2.80	1 : 3	151.4	146.5	126.0	21.25	19.07	14.09
2.80	1 : 4	147.4	141.4	126.0	17.58	16.17	12.60
3.50	1 : 2	118.5	104.6	81.96	16.84	14.25	9.29
3.50	1 : 3	92.76	87.9	82.33	10.10	8.94	6.58
3.50	1 : 4	88.99	84.5	82.89	7.98	6.94	5.94
4.20	1 : 2	504.1	60.1	46.66	8.39	6.99	3.37
4.20	1 : 3	504.1	52.8	52.22	3.43	3.05	2.02
4.20	1 : 4	504.1	54.3	53.37	2.78	2.49	1.87

Table (A2.9): Bending Moment and Deflection
7.0m Free Height Wall

2. Disscusion and Analysis of Results

2.1. Analysis of Wall Group No. (1) with Zero Top Berm Width

2.1.1. Analysis of Bending Moment Results

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Mb/M)^{1/3}$	Hw=5.00 $(Mb/M)^{1/3}$	Hw=7.00 $(Mb/M)^{1/3}$
0.20	1 : 2	0.95	0.93	0.93
0.20	1 : 3	0.94	0.90	0.91
0.20	1 : 4	0.91	0.88	0.89
0.30	1 : 2	0.91	0.87	0.86
0.30	1 : 3	0.89	0.83	0.81
0.30	1 : 4	0.86	0.79	0.78
0.40	1 : 2	0.86	0.80	0.77
0.40	1 : 3	0.82	0.73	0.71
0.40	1 : 4	0.80	0.71	0.69
0.50	1 : 2	0.80	0.71	0.69
0.50	1 : 3	0.75	0.64	0.62
0.50	1 : 4	0.73	0.62	0.59
0.60	1 : 2	0.74	0.63	0.59
0.60	1 : 3	0.69	0.56	0.52
0.60	1 : 4	0.69	0.54	0.50

Table (10): Comparison between Bending Moment Ratios

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		h_{em}	$(h_{em}/Hw)^{1/3}$	H_{em}	$(h_{em}/Hw)^{1/3}$	H_{em}	$(h_{em}/Hw)^{1/3}$
0.20	1 : 2	0.30	0.47	0.40	0.43	0.51	0.42
0.2	1 : 3	0.34	0.48	0.53	0.47	0.69	0.46
0.20	1 :4	0.52	0.56	0.63	0.50	0.88	0.50
0.30	1 : 2	0.51	0.55	0.73	0.53	1.09	0.54
0.30	1 : 3	0.63	0.59	0.97	0.58	1.50	0.60
03.0	1 :4	0.79	0.64	1.21	0.62	1.72	0.63
0.40	1 : 2	0.79	0.64	1.14	0.61	1.74	0.63
0.40	1 : 3	0.96	0.68	1.59	0.68	2.26	0.69
0.40	1 :4	1.08	0.71	1.74	0.70	2.43	0.70
0.50	1 : 2	1.07	0.71	1.72	0.70	2.44	0.70
0.50	1 : 3	1.31	0.76	2.19	0.76	3.03	0.76
0.50	1 :4	1.37	0.77	2.28	0.77	3.32	0.78
0.60	1 : 2	1.34	0.76	2.26	0.77	3.27	0.78
0.60	1 : 3	1.51	0.80	2.63	0.81	3.86	0.82
0.60	1 :4	1.54	0.80	2.71	0.82	4.00	0.83

Table (A2.11): Comparison between equivalent Height Moment Ratios

2.1.2. Analysis of Deflection Results

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Db/D)^{1/4}$	Hw=5.00 $(Db/D)^{1/4}$	Hw=7.00 $(Db/D)^{1/4}$
0.20	1 : 2	0.47	0.43	0.42
0.20	1 : 3	0.48	0.47	0.46
0.20	1 : 4	0.56	0.50	0.50
0.30	1 : 2	0.55	0.53	0.54
0.30	1 : 3	0.59	0.58	0.60
0.30	1 : 4	0.64	0.62	0.63
0.40	1 : 2	0.64	0.61	0.63
0.40	1 : 3	0.68	0.68	0.69
0.40	1 : 4	0.71	0.70	0.70
0.50	1 : 2	0.71	0.70	0.70
0.50	1 : 3	0.76	0.76	0.76
0.50	1 : 4	0.77	0.77	0.78
0.60	1 : 2	0.76	0.77	0.78
0.60	1 : 3	0.80	0.81	0.82
0.60	1 : 4	0.80	0.82	0.83

Table (A2.12): Comparison between Deflection Ratios

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$
0.20	1 : 2	0.08	0.41	0.28	0.48	0.34	0.47
0.2	1 : 3	0.19	0.50	0.37	0.52	0.49	0.51
0.20	1 :4	0.35	0.58	0.46	0.55	0.71	0.57
0.30	1 : 2	0.21	0.51	0.51	0.57	0.83	0.59
0.30	1 : 3	0.39	0.60	0.71	0.61	1.19	0.64
03.0	1 :4	0.60	0.67	0.95	0.66	1.45	0.68
0.40	1 : 2	0.41	0.61	0.83	0.64	1.36	0.66
0.40	1 : 3	0.71	0.70	1.28	0.71	1.88	0.72
0.40	1 :4	0.96	0.75	1.55	0.75	2.19	0.75
0.50	1 : 2	0.70	0.69	1.33	0.72	1.96	0.73
0.50	1 : 3	1.13	0.78	1.94	0.79	2.64	0.78
0.50	1 :4	1.34	0.82	2.21	0.81	3.02	0.81
0.60	1 : 2	1.05	0.77	1.88	0.78	2.64	0.78
0.60	1 : 3	1.43	0.83	2.78	0.86	3.37	0.83
0.60	1 :4	1.67	0.86	2.81	0.87	3.53	0.84

Table (A2.13): Comparison between Equivalent Height Deflection Ratios

2.2. Analysis of Wall Group No. (2) with Zero Top Berm Width

2.2.1. Analysis of Bending Moment Results

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Mb/M)^{1/3}$	Hw=5.00 $(Mb/M)^{1/3}$	Hw=7.00 $(Mb/M)^{1/3}$
0.20	1 : 2	0.97	0.95	0.93
0.20	1 : 3	0.96	0.93	0.91
0.20	1 : 4	0.94	0.91	0.90
0.30	1 : 2	0.94	0.90	0.88
0.30	1 : 3	0.91	0.87	0.83
0.30	1 : 4	0.90	0.84	0.80
0.40	1 : 2	0.90	0.85	0.79
0.40	1 : 3	0.87	0.78	0.73
0.40	1 : 4	0.86	0.76	0.70
0.50	1 : 2	0.86	0.77	0.71
0.50	1 : 3	0.82	0.70	0.63
0.50	1 : 4	0.81	0.68	0.61
0.60	1 : 2	0.80	0.70	0.61
0.60	1 : 3	0.77	0.62	0.54
0.60	1 : 4	0.75	0.60	0.53

Table (A2.14): Comparison between Bending Moment Ratios

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		h_{em}	$(h_{em}/Hw)^{1/3}$	H_{em}	$(h_{em}/Hw)^{1/3}$	H_{em}	$(h_{em}/Hw)^{1/3}$
0.20	1 : 2	0.25	0.44	0.38	0.42	0.55	0.43
0.2	1 : 3	0.40	0.51	0.57	0.49	0.74	0.47
0.20	1 :4	0.51	0.55	0.71	0.52	0.81	0.49
0.30	1 : 2	0.53	0.56	0.78	0.54	1.02	0.53
0.30	1 : 3	0.69	0.61	1.05	0.59	1.02	0.53
03.0	1 :4	0.77	0.64	1.21	0.62	1.66	0.62
0.40	1 : 2	0.81	0.65	1.18	0.62	1.77	0.63
0.40	1 : 3	0.95	0.68	1.59	0.68	2.27	0.69
0.40	1 :4	1.05	0.70	1.74	0.70	2.45	0.70
0.50	1 : 2	1.06	0.71	1.67	0.69	2.39	0.70
0.50	1 : 3	1.25	0.75	2.10	0.75	2.94	0.75
0.50	1 :4	1.33	0.76	2.23	0.76	3.07	0.76
0.60	1 : 2	1.34	0.76	2.11	0.75	3.07	0.76
0.60	1 : 3	1.52	0.80	2.62	0.81	3.46	0.79
0.60	1 :4	1.59	0.81	2.76	0.82	3.53	0.80

Table (A2.15): Comparison between equivalent Height Moment Ratios

2.2.2. Analysis of Deflection Results

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Db/D)^{1/4}$	Hw=5.00 $(Db/D)^{1/4}$	Hw=7.00 $(Db/D)^{1/4}$
0.20	1 : 2	0.97	0.95	0.95
0.20	1 : 3	0.93	0.93	0.93
0.20	1 : 4	0.91	0.90	0.90
0.30	1 : 2	0.92	0.90	0.90
0.30	1 : 3	0.88	0.86	0.86
0.30	1 : 4	0.84	0.83	0.81
0.40	1 : 2	0.86	0.84	0.82
0.40	1 : 3	0.81	0.77	0.75
0.40	1 : 4	0.76	0.73	0.70
0.50	1 : 2	0.80	0.77	0.75
0.50	1 : 3	0.72	0.68	0.65
0.50	1 : 4	0.66	0.62	0.60
0.60	1 : 2	0.71	0.70	0.65
0.60	1 : 3	0.63	0.55	0.54
0.60	1 : 4	0.54	0.48	0.48

Table (A2.16): Comparison between Deflection Ratios

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$
0.20	1 : 2	0.12	0.450	0.22	0.459	0.279	0.447
0.2	1 : 3	0.24	0.533	0.34	0.510	0.413	0.493
0.20	1 :4	0.31	0.568	0.47	0.554	0.575	0.535
0.30	1 : 2	0.27	0.546	0.48	0.558	0.623	0.546
0.30	1 : 3	0.43	0.614	0.70	0.612	0.934	0.604
03.0	1 :4	0.53	0.648	0.88	0.648	1.319	0.659
0.40	1 : 2	0.47	0.631	0.79	0.630	1.257	0.651
0.40	1 : 3	0.65	0.681	1.18	0.697	1.757	0.708
0.40	1 :4	0.81	0.721	1.44	0.733	2.116	0.741
0.50	1 : 2	0.67	0.689	1.20	0.699	1.793	0.711
0.50	1 : 3	0.98	0.755	1.73	0.767	2.474	0.771
0.50	1 :4	1.23	0.801	2.07	0.802	3.180	0.821
0.60	1 : 2	1.02	0.764	1.62	0.754	2.486	0.772
0.60	1 : 3	1.39	0.825	2.44	0.835	3.671	0.851
0.60	1 :4	1.64	0.860	2.75	0.861	4.047	0.873

Table (A2.17): Comparison between Equivalent Height Deflection Ratios

2.3. Analysis of Wall Group No. (1) with Different Top Berm Widths

2.3.1. Analysis of Bending Moment Results

Berm to wall height Ratio (Hb/Hw)	Slope .m	Bt=0.00 $(Mb/M)^{1/3}$	Bt=1.00 $(Mb/M)^{1/3}$	Bt=1.50 $(Mb/M)^{1/3}$	Bt=3.00 $(Mb/M)^{1/3}$
0.20	1 : 2	0.94	0.90	0.88	0.84
0.20	1 : 3	0.92	0.88	0.86	0.84
0.20	1 : 4	0.89	0.87	0.85	0.84
0.30	1 : 2	0.88	0.83	0.81	0.77
0.30	1 : 3	0.84	0.79	0.78	0.77
0.30	1 : 4	0.81	0.78	0.78	0.77
0.40	1 : 2	0.81	0.75	0.72	0.69
0.40	1 : 3	0.75	0.71	0.70	0.68
0.40	1 : 4	0.73	0.70	0.69	0.69
0.50	1 : 2	0.73	0.66	0.63	0.61
0.50	1 : 3	0.67	0.62	0.61	0.62
0.50	1 : 4	0.65	0.62	0.61	0.61
0.60	1 : 2	0.65	0.57	0.55	0.53
0.60	1 : 3	0.59	0.55	0.54	0.55
0.60	1 : 4	0.58	0.55	0.54	0.55

Table (A2.18): Comparison between bending Moment Ratios

2.3.2. Analysis of Deflection Results

Berm to wall height Ratio (Hb/Hw)	Slope .m	Bt=0.00 $(Db/D)^{1/4}$	Bt=1.00 $(Db/D)^{1/4}$	Bt=1.50 $(Db/D)^{1/4}$	Bt=3.00 $(Db/D)^{1/4}$
0.20	1 : 2	0.95	0.90	0.87	0.82
0.20	1 : 3	0.92	0.89	0.85	0.81
0.20	1 : 4	0.88	0.85	0.83	0.80
0.30	1 : 2	0.89	0.83	0.80	0.73
0.30	1 : 3	0.84	0.78	0.76	0.71
0.30	1 : 4	0.79	0.75	0.74	0.70
0.40	1 : 2	0.82	0.75	0.70	0.63
0.40	1 : 3	0.74	0.67	0.65	0.60
0.40	1 : 4	0.69	0.64	0.62	0.59
0.50	1 : 2	0.74	0.64	0.60	0.50
0.50	1 : 3	0.64	0.55	0.53	0.45
0.50	1 : 4	0.58	0.52	0.49	0.50
0.60	1 : 2	0.65	0.52	0.52	0.41
0.60	1 : 3	0.52	0.43	0.41	0.36
0.60	1 : 4	0.47	0.37	0.39	0.36

Table (A2.19): Comparison between Deflection Ratios

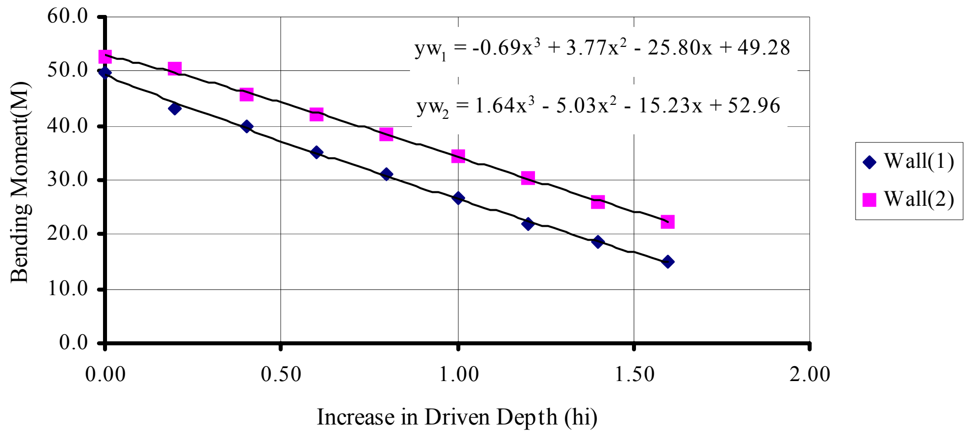

Figure (A2.1): Maximum Moment versus Increase in Driven Depth
(Hw=3.00m & φ =30°)

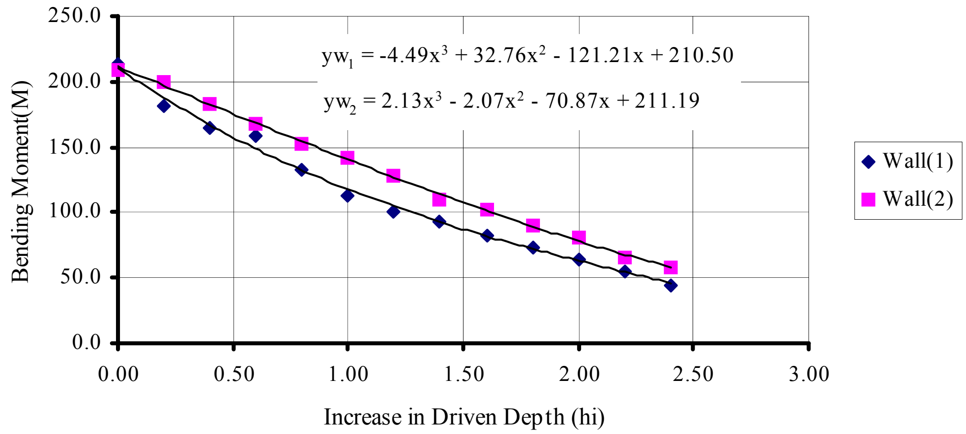

Figure (A2.2): Maximum Moment versus Increase in Driven Depth
(Hw=5.00m & φ =30°)

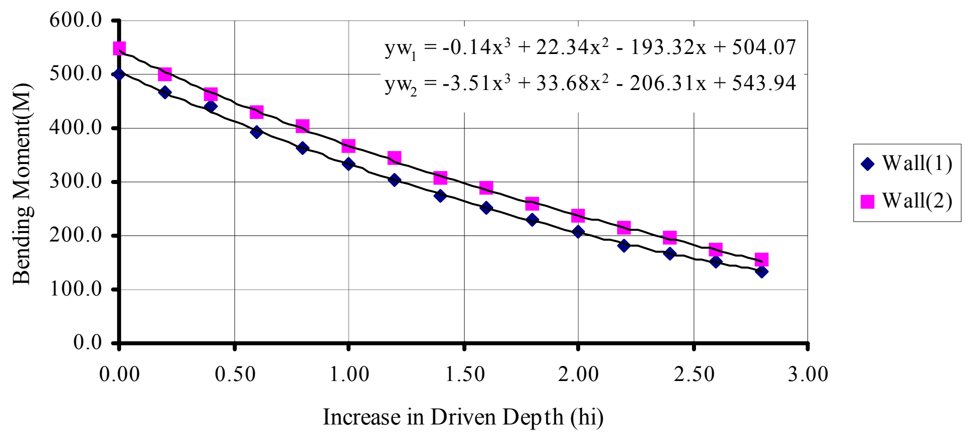

Figure (A2.3): Maximum Moment versus Increase in Driven Depth
(Hw=7.00m & φ =30°)

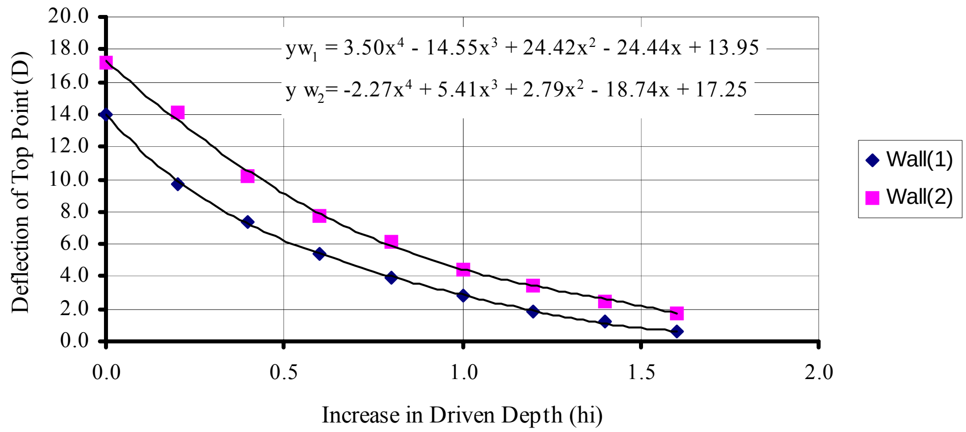

Figure (A2.4): The Deflection of the Wall versus Increase of Driven Depth (Hw=3.00m & φ =30°)

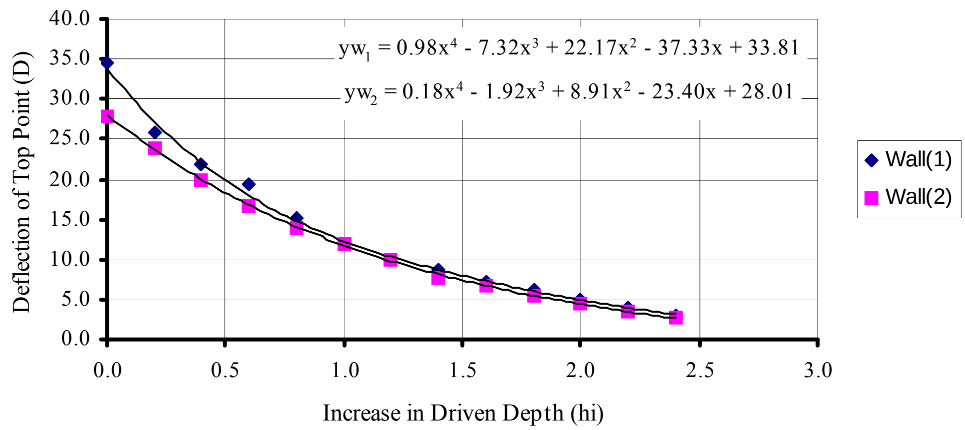

Figure (A2.5): The Deflection of the Wall versus Increase of Driven Depth (Hw=5.00m & φ =30°)

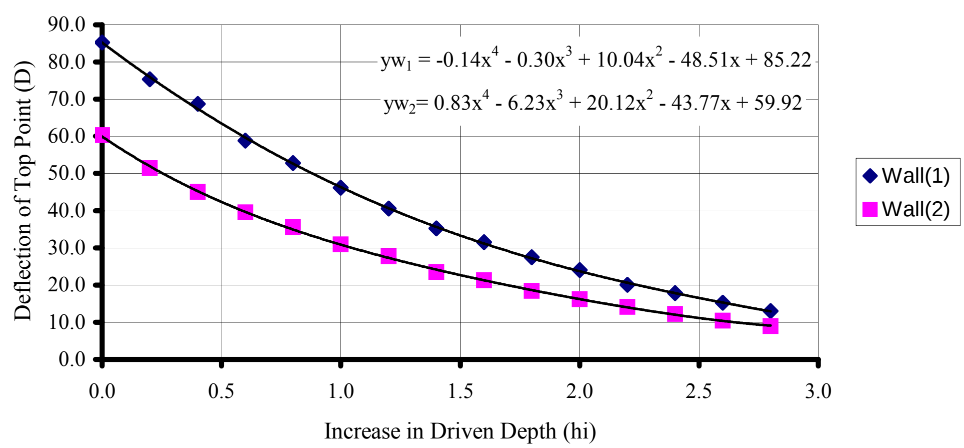

Figure (A2.6): The Deflection of the Wall versus Increase of Driven Depth (Hw=7.00m & φ =30°)

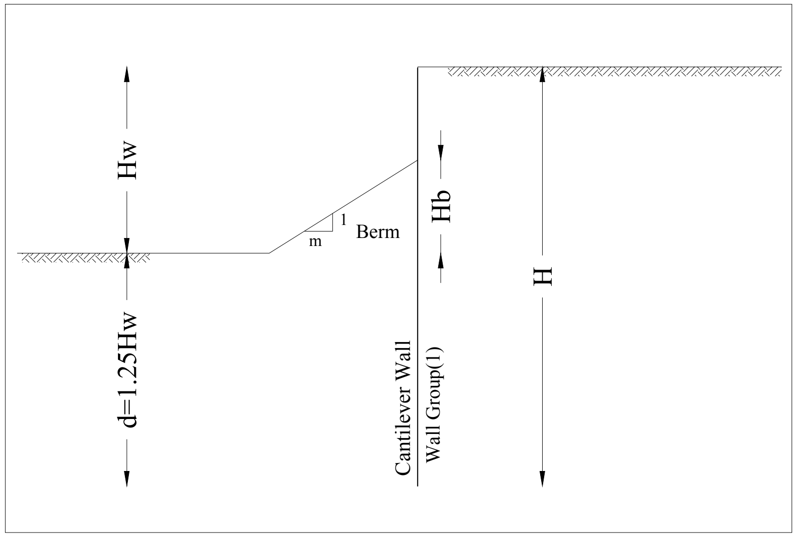

Figure (A2.7): Geometry of the Bermed Wall with Zero Top Width

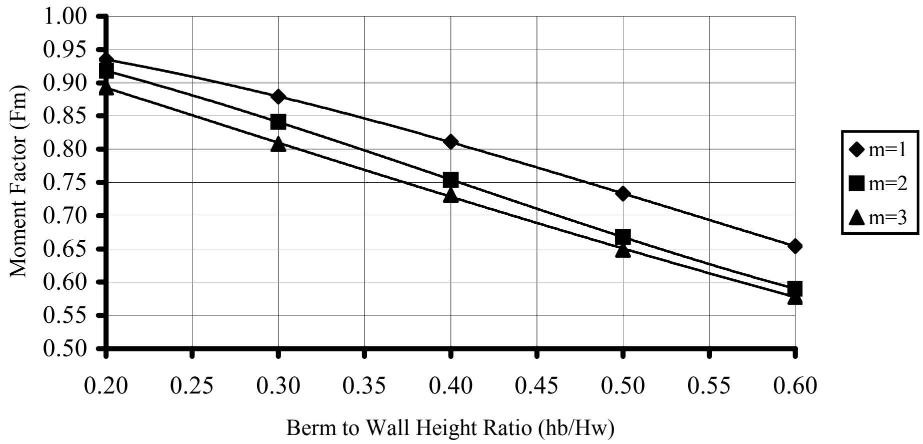

Figure (A2.8): Moment Factor versus Berm to Wall Height Ratio
(φ =30° & Wall Group No. (1))

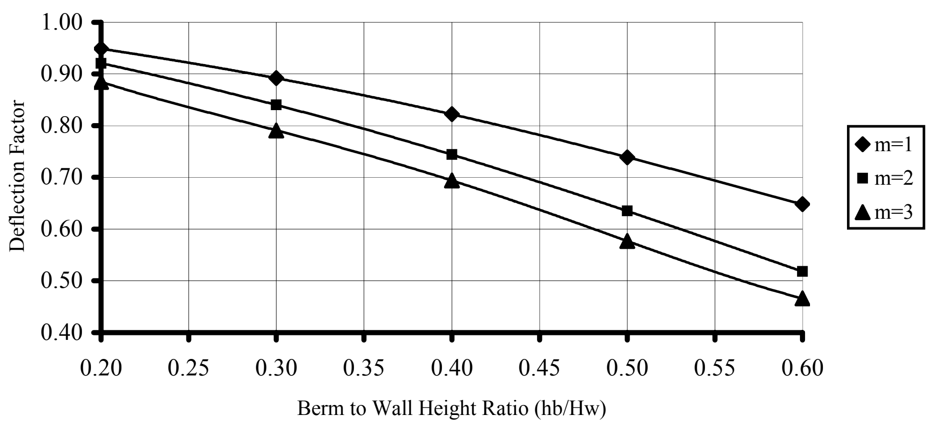

Figure (A2.9): Deflection Factor versus Berm to Wall Height Ratio
(φ =30° & Wall Group No. (1))

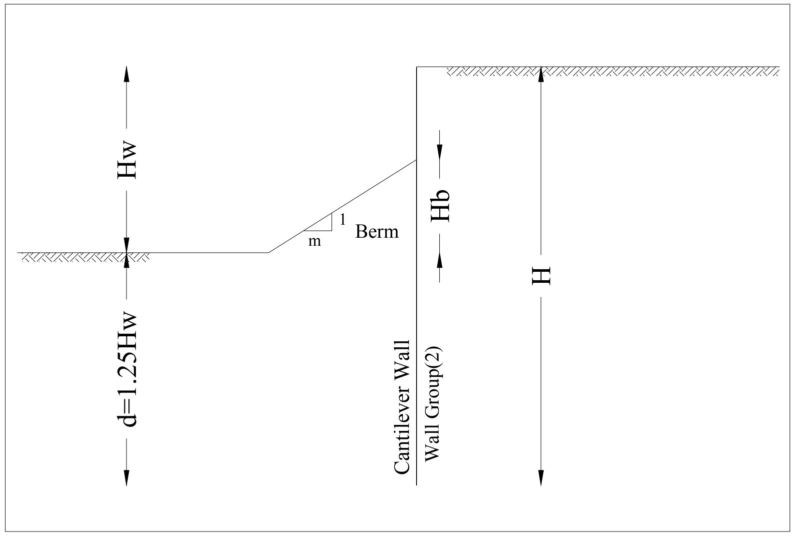

Figure (A2.10): Geometry of the Bermed Wall with Zero Top Width

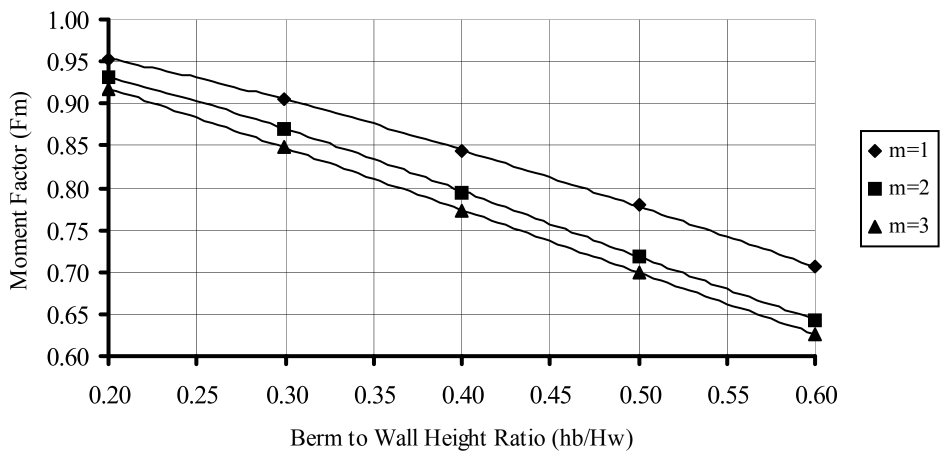

Figure (A2.11): Moment Factor versus Berm to Wall Height Ratio
(φ =30° & Wall Group No. (2))

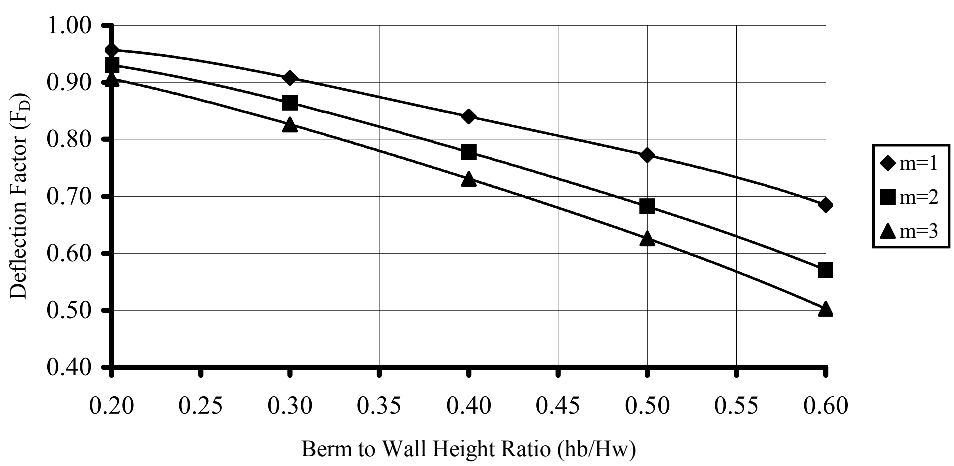

Figure (A2.12): Deflection Factor versus Berm to Wall Height Ratio
(φ =30° & Wall Group No. (2))

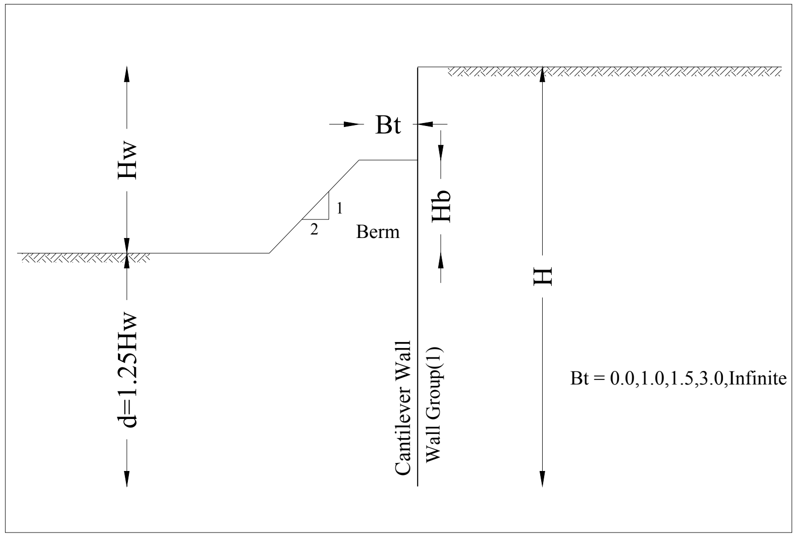

Figure (A2.13): Geometry of the Bermed Wall with Different Top Berm Widths

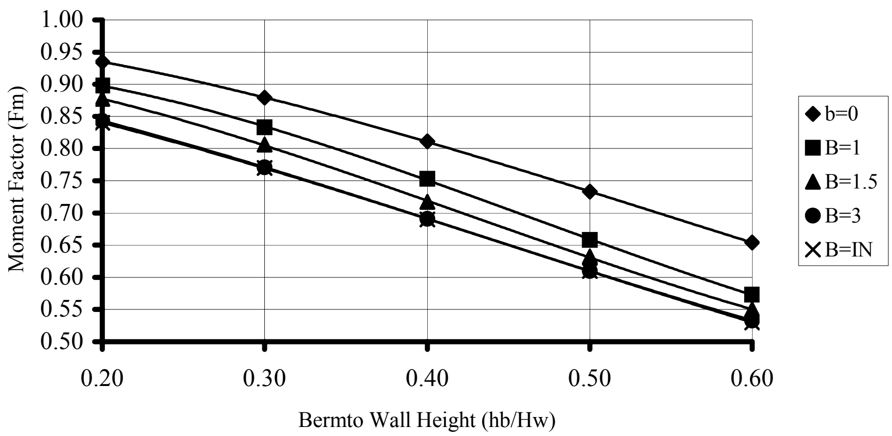

Figure (A2.14): Moment Factor versus Berm to Wall Height Ratio
(φ =30° & Wall Group No. (1))

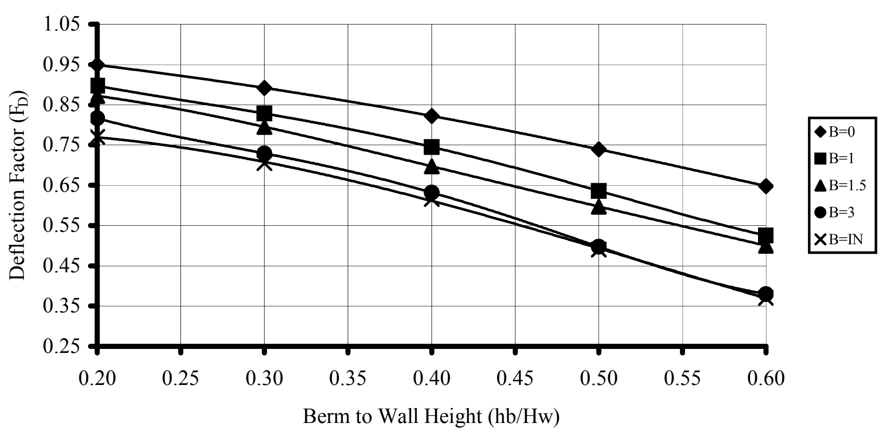

Figure (A2.15): Deflection Factor versus Berm to Wall Height Ratio
(φ =30° & Wall Group No. (1))

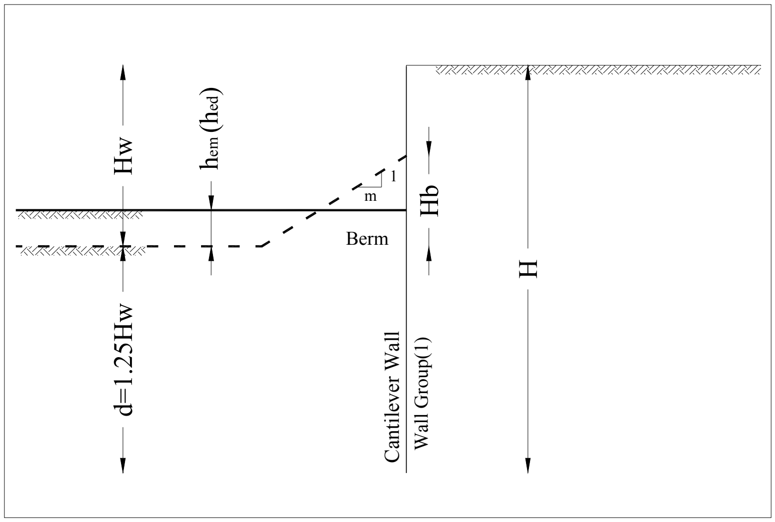

Figure (A2.16): Geometry of Bermed Wall with Zero Top Width

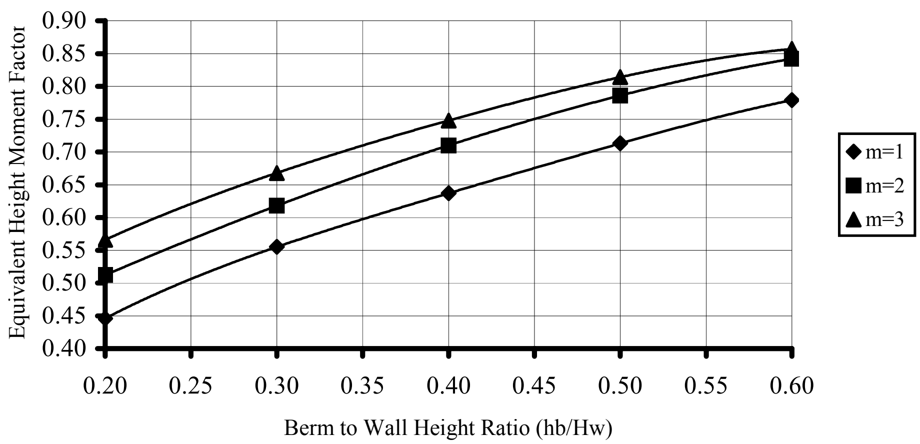

Figure (A2.17): Equivalent Height Moment Factor versus Wall to Berm Height Ratio (φ =30°&Wall Group (1))

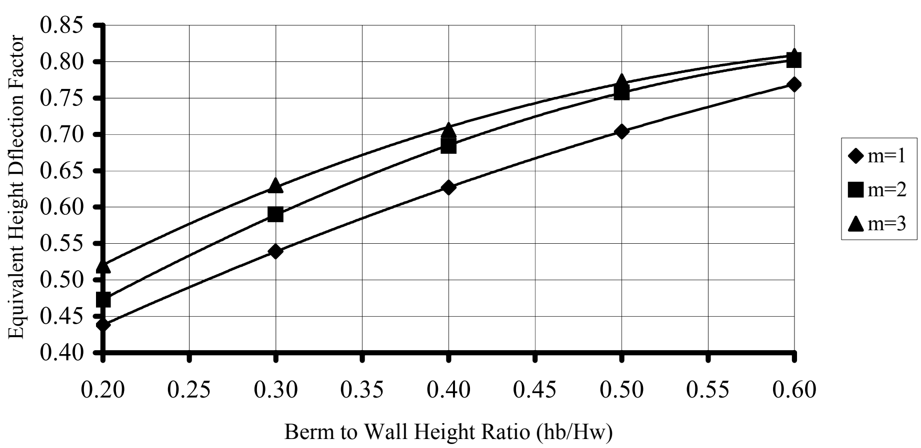

Figure (A2.18): Equivalent Height Deflection Factor versus Wall to Berm Height Ratio (φ =30°&Wall Group (1))

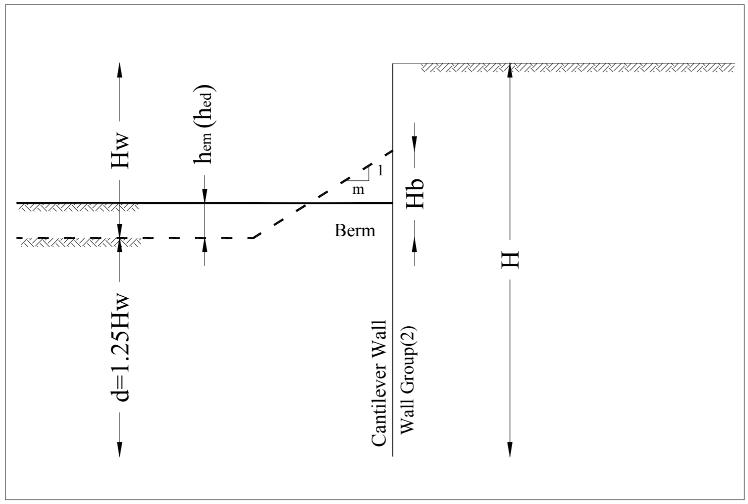

Figure (A2.19): Geometry of the Bermed Wall with Zero Top Width

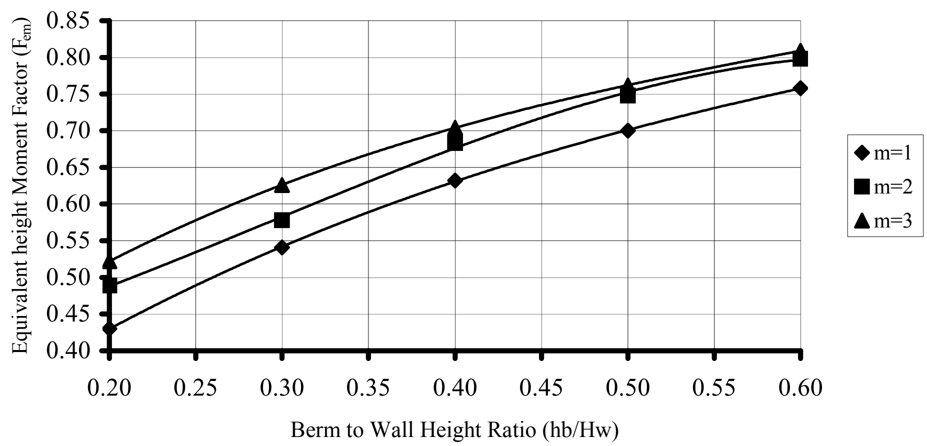

Figure (A2.20): Equivalent Height Moment Factor versus Wall to Berm Height Ratio
(φ =30°&Wall Group (2))

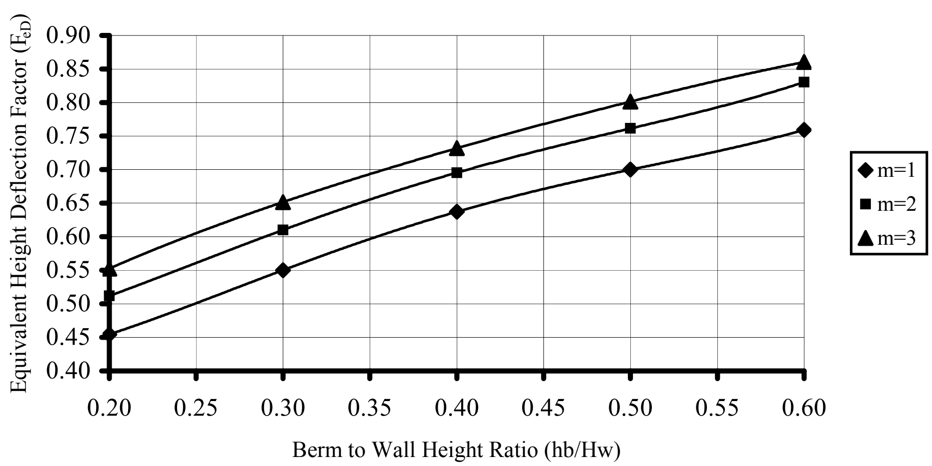

Figure (A2.21): Equivalent Height Deflection Factor versus Wall to Berm Height Ratio
(φ =30°&Wall Group (2))

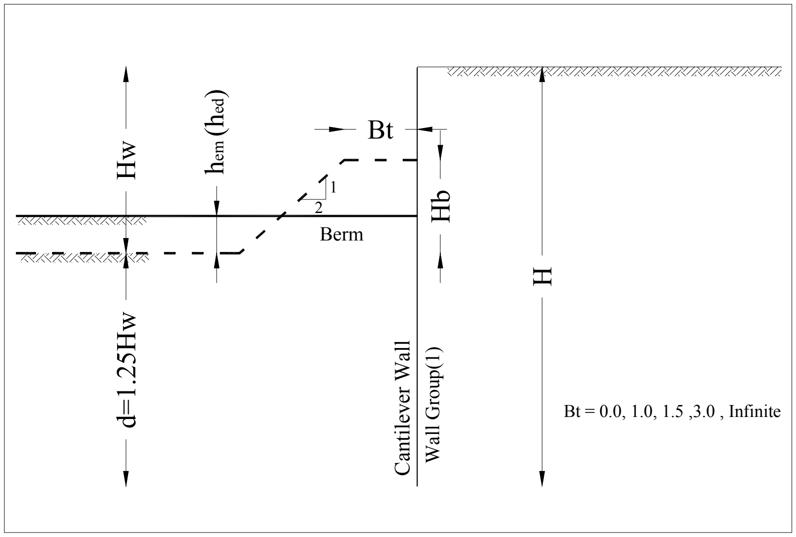

Figure (A2.22): Geometry of the Bermed Wall with Different Top Berm Widths

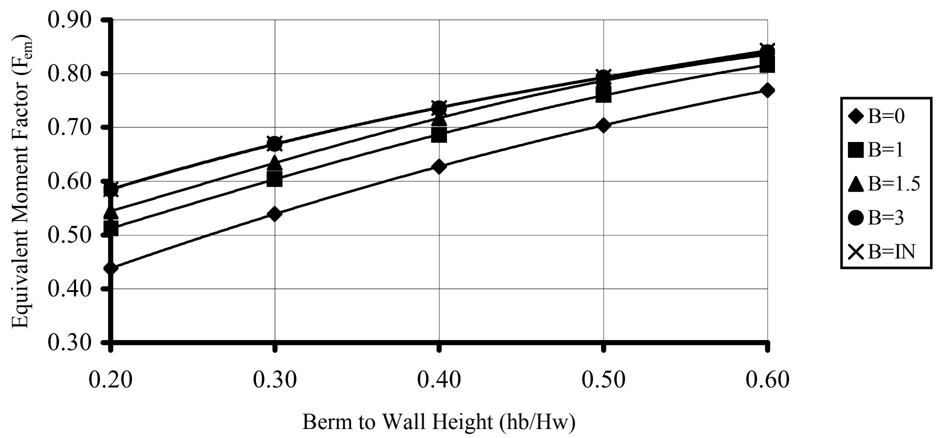

Figure (A2.23): Equivalent Height Moment Factor versus Wall to Berm Height Ratio
(φ =30° & Wall Group No. (1))

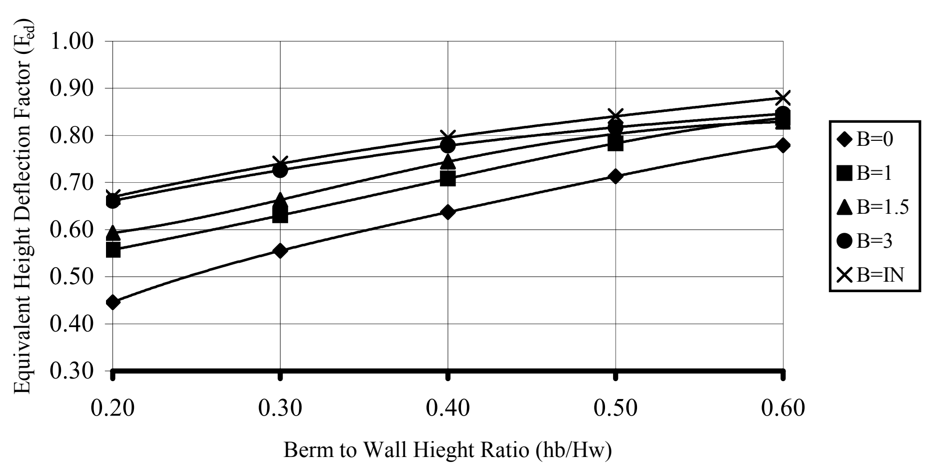

Figure (A2.24): Equivalent Height Deflection Factor versus Wall to Berm Height Ratio
(φ =30° & Wall Group No. (1))

APPENDIX (3)

RESULTS OF SOIL GROUP (3)

(φ=32°)

1. Numerical Results from Finite Element Analysis

1.1. Effect of Varying Driven Depth of the Wall

Increase in Driven depth (m)	Wall Group(1)		Wall Group(2)	
	Moment (KN.m/m')	Deflection (mm)	Moment (KN.m/m')	Deflection (mm)
0.00	43.58	9.26	47.82	11.38
0.20	40.33	7.18	46.57	10
0.40	36.56	5.38	42.93	7.26
0.60	32.04	4.00	39.02	5.65
0.80	28.37	2.93	35.69	4.28
1.00	23.28	1.92	31.72	3.25
1.20	19.37	1.23	27.96	2.49
1.40	16.17	0.71	24.3	1.79
1.60	14.13	0.42	20.8	1.29

Table (A3.1): Bending Moment and Deflection
3.0m Initial Free Height Wall

Increase in Driven depth (m)	Wall Group(1)		Wall Group(2)	
	Moment (KN.m/m')	Deflection (mm)	Moment (KN.m/m')	Deflection (mm)
0.00	173.000	23.800	193.06	21.65
0.20	156.57	19.14	179.01	17.61
0.40	146.98	16.89	164.08	14.85
0.60	129.29	13.78	150.01	12.55
0.80	114.99	11.56	136.11	10.52
1.00	102.77	9.64	125.4	9.13
1.20	90.58	8.01	113.7	7.66
1.40	81.30	6.82	101.48	6.36
1.60	73.24	5.82	90.14	5.17
1.80	64.47	4.83	80.15	4.18
2.00	54.66	3.48	71.42	3.44
2.20	47.29	3.09	58.41	2.57
2.40	40.87	2.47	53.78	2.19

Table (A3.2): Bending Moment and Deflection
5.0m Initial Free Height Wall

Increase in Driven depth (m)	Wall Group(1)		Wall Group(2)	
	Moment (KN.m/m’)	Deflection (mm)	Moment (KN.m/m’)	Deflection (mm)
0.00	434.20	66.57	479.600	46.240
0.20	400.16	58.91	441.840	40.230
0.40	368.53	52.26	410.560	35.500
0.60	352.64	48.36	382.170	31.770
0.80	318.19	42.23	355.090	28.070
1.00	288.12	36.49	332.110	25.370
1.20	258.30	31.72	299.510	21.890
1.40	238.32	28.17	275.780	19.300
1.60	218.57	24.84	250.700	16.960
1.80	200.95	22.16	230.340	14.910
2.00	183.83	19.36	210.040	13.170
2.20	161.69	16.29	185.440	11.100
2.40	146.86	14.20	170.630	9.840
2.60	130.73	12.04	154.470	8.550
2.80	115.94	10.18	139.540	7.390

Table (A3.3): Bending Moment and Deflection
7.0m Initial Free Height Wall

1.2. Results of Wall with Stabilizing Berm

1.2.1. Results of Wall with Zero Top Berm Width

Berm Height (m)	Berm Slope VL. To HL.	Wall Group No.(1)		Wall Group No.(2)	
		Moment (kN.m/m’)	Deflection (mm)	Moment (kN.m/m’)	Deflection (mm)
0.60	1 : 2	37.53	7.00	43.85	10.16
0.60	1 : 3	35.26	6.20	42.16	8.88
0.60	1 : 4	34.16	5.71	40.68	7.97
0.90	1 : 2	33.21	5.67	39.92	8.39
0.90	1 : 3	29.92	4.51	37.59	6.86
0.90	1 : 4	28.33	3.77	35.81	5.95
1.20	1 : 2	27.86	4.15	35.62	6.64
1.20	1 : 3	24.00	2.81	31.33	4.61
1.20	1 : 4	22.65	2.04	30.58	3.74
1.50	1 : 2	22.29	2.64	30.21	4.80
1.50	1 : 3	18.53	1.29	26.68	2.96
1.50	1 : 4	17.75	0.62	25.53	2.09
1.80	1 : 2	17.29	1.39	25.62	3.20
1.80	1 : 3	14.68	0.34	21.90	1.46
1.80	1 : 4	14.04	0.00	20.89	0.71

Table (A3.4): Bending Moment and Deflection
3.0m Free Height Wall

Berm Height (m)	Berm Slope VL. To HL.	Wall group No.(1)		Wall group No.(2)	
		Moment (kN.m/m')	Deflection (mm)	Moment (kN.m/m')	Deflection (mm)
1.00	1 : 2	152.61	19.81	162.67	16.98
1.00	1 : 3	135.81	17.06	148.06	14.87
1.00	1 : 4	128.85	15.85	142.23	13.64
1.20	1 : 2	117.37	14.39	136.62	13.31
1.20	1 : 3	97.97	11.13	117.70	10.77
1.20	1 : 4	88.68	9.31	109.64	9.22
1.50	1 : 2	86.57	9.73	107.78	9.77
1.50	1 : 3	69.63	6.85	88.50	6.99
1.50	1 : 4	62.79	5.34	81.39	5.54
1.50	1 : 2	60.98	6.18	81.26	6.63
1.50	1 : 3	47.50	3.62	63.38	3.97
1.50	1 : 4	44.33	2.63	57.55	2.40
1.80	1 : 2	41.44	3.54	56.55	3.64
1.80	1 : 3	31.30	1.76	43.80	1.38
1.80	1 : 4	29.95	1.74	41.00	0.88

Table (A3.5): Bending Moment and Deflection
5.0m Free Height Wall

Berm Height (m)	Berm Slope VL. To HL.	Wall group No.(1)		Wall group No.(2)	
		Moment (KN.m/m')	Deflection (mm)	Moment (kN.m/m')	Deflection (mm)
1.40	1 : 2	351.39	53.560	379.12	36.58
1.40	1 : 3	313.68	46.610	350.13	33.05
1.40	1 : 4	292.45	42.010	337.06	30.16
2.10	1 : 2	265.45	38.890	304.96	28.38
2.10	1 : 3	234.89	33.160	266.35	23.67
2.10	1 : 4	197.63	25.460	231.71	18.32
2.80	1 : 2	191.62	26.850	230.66	20.43
2.80	1 : 3	155.31	19.510	179.53	13.99
2.80	1 : 4	136.03	14.780	161.90	10.75
3.50	1 : 2	129.38	16.970	154.70	12.47
3.50	1 : 3	94.86	9.480	118.13	7.43
3.50	1 : 4	89.38	7.330	109.02	5.46
4.20	1 : 2	79.76	9.270	102.61	7.33
4.20	1 : 3	59.93	3.840	75.96	3.05
4.20	1 : 4	56.73	2.588	71.42	1.94

Table (A3.6): Bending Moment and Deflection
7.0m Free Height Wall

1.2.2. Results of Wall with Different Top Berm Widths

Berm height (m)	Berm slope VL. To HL.	Moment (KN.m/m')			Deflection (mm)		
		Bt=1.0	Bt=1.5	Bt=3.0	Bt=1.0	Bt=1.5	Bt=3.0
0.60	1 : 2	34.75	30.71	28.62	6.350	4.53	2.810
0.60	1 : 3	30.70	30.28	28.38	4.65	4.32	2.630
0.60	1 : 4	30.78	30.73	28.33	4.54	4.18	2.540
0.90	1 : 2	26.45	25.44	23.80	3.59	3.08	1.530
0.90	1 : 3	25.54	25.35	24.69	2.97	2.56	1.640
0.90	1 : 4	25.72	25.56	23.69	2.68	2.31	1.330
1.20	1 : 2	21.30	20.06	19.73	2.13	1.56	0.563
1.20	1 : 3	20.23	19.70	20.38	1.50	1.32	0.575
1.20	1 : 4	20.36	20.70	20.49	1.18	1.26	0.578
1.50	1 : 2	16.31	15.70	16.12	1.03	0.71	-
1.50	1 : 3	16.22	16.09	16.60	0.38	0.26	-
1.50	1 : 4	16.67	16.96	15.99	0.23	0.07	-
1.80	1 : 2	13.09	12.29	11.84	0.12	-	-
1.80	1 : 3	12.56	12.13	12.07	-	-	-
1.80	1 : 4	12.66	13.02	12.13	-	-	-

Table (A3.7): Bending Moment and Deflection
3.0m Free Height Wall

Berm height (m)	Berm slope VL. To HL.	Moment (kN.m/m')			Deflection (mm)		
		Bt=1.0	Bt=1.5	Bt=3.0	Bt=1.0	Bt=1.5	Bt=3.0
1.00	1 : 2	131.7	121.8	87.47	16.67	15.03	8.640
1.00	1 : 3	126.5	103.9	85.05	15.72	11.76	7.710
1.00	1 : 4	117.5	175.3	85.95	13.84	9.54	7.750
1.50	1 : 2	101.8	81.97	62.96	12.01	8.98	4.790
1.50	1 : 3	81.26	75.75	63.72	8.46	7.41	4.830
1.50	1 : 4	77.03	73.90	64.09	7.31	6.64	4.370
2.00	1 : 2	63.96	57.36	46.21	6.52	5.40	2.720
2.00	1 : 3	56.19	53.90	46.42	4.77	4.45	2.280
2.00	1 : 4	55.22	53.14	48.45	4.09	3.63	2.390
2.50	1 : 2	42.40	39.04	32.87	3.47	3.21	0.868
2.50	1 : 3	38.71	37.56	30.73	2.28	1.82	0.421
2.50	1 : 4	39.12	37.06	31.44	1.99	1.48	0.559
3.00	1 : 2	28.08	24.84	23.78	1.85	1.27	-
3.00	1 : 3	26.18	25.76	24.27	0.42	0.23	-
3.00	1 : 4	26.66	26.12	24.93	0.31	0.24	-

Table (A3.8): Bending Moment and Deflection
5.0m Free Height Wall

Berm height (m)	Berm slope VL. To HL.	Moment (kN.m/m')			Deflection (mm)		
		Bt=1.0	**Bt=1.5**	**Bt=3.0**	**Bt=1.0**	**Bt=1.5**	**Bt=3.0**
1.40	1 : 2	305.9	280.3	222.3	45.76	40.43	28.52
1.40	1 : 3	292.8	275.4	211.1	43.04	39.90	25.73
1.40	1 : 4	273.2	259.9	222.6	38.85	35.93	26.38
2.10	1 : 2	227.8	218.5	151.2	32.65	31.14	17.15
2.10	1 : 3	205.3	194.5	148.8	27.78	25.45	15.37
2.10	1 : 4	193.0	184.0	149.4	24.05	22.33	14.64
2.80	1 : 2	173.7	155.3	108.8	23.70	20.58	10.71
2.80	1 : 3	132.6	125.9	92.66	15.34	13.97	6.97
2.80	1 : 4	126.1	114.7	103.8	12.89	10.97	7.77
3.50	1 : 2	93.74	82.47	61.39	11.29	9.30	3.55
3.50	1 : 3	79.75	74.95	63.86	6.93	5.86	2.88
3.50	1 : 4	75.88	73.50	69.36	5.23	4.70	3.25
4.20	1 : 2	54.05	46.16	41.02	4.95	3.59	0.59
4.20	1 : 3	49.30	47.27	39.22	2.14	1.66	0.54
4.20	1 : 4	49.47	48.20	43.54	1.65	1.36	0.52

Table (A3.9): Bending Moment and Deflection
7.0m Free Height Wall

2. Disscusion and Analysis of Results

2.1. Analysis of Wall Group No. (1) with Zero Top Berm Width

2.1.1. Analysis of Bending Moment Results

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Mb/M)^{1/3}$	Hw=5.00 $(Mb/M)^{1/3}$	Hw=7.00 $(Mb/M)^{1/3}$
0.20	1 : 2	0.952	0.955	0.932
0.20	1 : 3	0.932	0.918	0.897
0.20	1 : 4	0.923	0.903	0.877
0.30	1 : 2	0.914	0.875	0.849
0.30	1 : 3	0.883	0.824	0.815
0.30	1 : 4	0.867	0.797	0.769
0.40	1 : 2	0.862	0.790	0.761
0.40	1 : 3	0.820	0.735	0.710
0.40	1 : 4	0.805	0.710	0.679
0.50	1 : 2	0.800	0.703	0.668
0.50	1 : 3	0.752	0.647	0.602
0.50	1 : 4	0.742	0.632	0.590
0.60	1 : 2	0.735	0.618	0.568
0.60	1 : 3	0.696	0.563	0.517
0.60	1 : 4	0.686	0.555	0.507

Table (A3.10): Comparison between Bending Moment Ratios

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		h_{em}	$(h_{em}/Hw)^{1/3}$	h_{em}	$(h_{em}/Hw)^{1/3}$	h_{em}	$(h_{em}/Hw)^{1/3}$
0.20	1 : 2	0.35	0.491	0.28	0.382	0.54	0.426
0.2	1 : 3	0.46	0.537	0.50	0.465	0.81	0.488
0.20	1 :4	0.51	0.556	0.60	0.494	0.98	0.518
0.30	1 : 2	0.56	0.571	0.77	0.537	1.19	0.555
0.30	1 : 3	0.71	0.617	1.09	0.603	1.46	0.593
03.0	1 :4	0.78	0.637	1.26	0.632	1.81	0.638
0.40	1 : 2	0.80	0.643	1.30	0.639	1.88	0.645
0.40	1 : 3	0.97	0.687	1.65	0.691	2.28	0.688
0.40	1 :4	1.04	0.702	1.81	0.713	2.53	0.712
0.50	1 : 2	1.06	0.706	1.85	0.718	2.62	0.721
0.50	1 : 3	1.25	0.748	2.20	0.761	3.18	0.768
0.50	1 :4	1.30	0.757	2.30	0.772	3.28	0.777
0.60	1 : 2	1.33	0.762	2.38	0.781	3.49	0.793
0.60	1 : 3	1.53	0.799	2.72	0.816	4.09	0.836
0.60	1 :4	1.60	0.811	2.77	0.821	4.15	0.846

Table (A3.11): Comparison between Equivalent Height Moment Ratios

2.1.2. Analysis of Deflection Results

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Db/D)^{1/4}$	Hw=5.00 $(Db/D)^{1/4}$	Hw=7.00 $(Db/D)^{1/4}$
0.20	1 : 2	0.932	0.968	0.948
0.20	1 : 3	0.904	0.933	0.916
0.20	1 : 4	0.886	0.916	0.892
0.30	1 : 2	0.884	0.894	0.875
0.30	1 : 3	0.835	0.838	0.841
0.30	1 : 4	0.799	0.802	0.787
0.40	1 : 2	0.818	0.811	0.798
0.40	1 : 3	0.742	0.743	0.737
0.40	1 : 4	0.685	0.698	0.687
0.50	1 : 2	0.731	0.724	0.711
0.50	1 : 3	0.611	0.633	0.615
0.50	1 : 4	0.508	0.585	0.577
0.60	1 : 2	0.622	0.630	0.612
0.60	1 : 3	0.439	0.528	0.491
0.60	1 : 4	0.350	0.527	0.445

Table (A3.12): Comparison between Deflection Ratios

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$
0.20	1 : 2	0.215	0.517	0.169	0.429	0.383	0.484
0.2	1 : 3	0.304	0.564	0.356	0.517	0.619	0.545
0.20	1 :4	0.363	0.590	0.445	0.546	0.789	0.579
0.30	1 : 2	0.368	0.592	0.560	0.579	0.912	0.601
0.30	1 : 3	0.525	0.647	0.853	0.643	1.162	0.638
03.0	1 :4	0.640	0.680	1.050	0.677	1.565	0.688
0.40	1 : 2	0.579	0.663	1.002	0.669	1.484	0.679
0.40	1 : 3	0.813	0.721	1.382	0.725	1.961	0.727
0.40	1 :4	0.979	0.756	1.651	0.758	2.354	0.762
0.50	1 : 2	0.847	0.729	1.493	0.739	2.162	0.746
0.50	1 : 3	1.180	0.792	2.056	0.801	2.857	0.799
0.50	1 :4	1.447	0.833	2.333	0.827	3.053	0.813
0.60	1 : 2	1.150	0.787	2.077	0.803	2.877	0.801
0.60	1 : 3	1.721	0.870	2.571	0.847	3.334	0.831
0.60	1 :4	1.731	0.880	2.574	0.847	3.584	0.846

Table (A3.13): Comparison between Equivalent Height Deflection Ratios

2.2. Analysis of Wall Group No. (2) with Zero Top Berm Width

2.2.1. Analysis of Bending Moment Results

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Mb/M)^{1/3}$	Hw=5.00 $(Mb/M)^{1/3}$	Hw=7.00 $(Mb/M)^{1/3}$
0.20	1 : 2	0.969	0.944	0.927
0.20	1 : 3	0.957	0.915	0.902
0.20	1 : 4	0.945	0.903	0.891
0.30	1 : 2	0.939	0.891	0.862
0.30	1 : 3	0.921	0.848	0.824
0.30	1 : 4	0.906	0.828	0.786
0.40	1 : 2	0.904	0.823	0.785
0.40	1 : 3	0.867	0.771	0.722
0.40	1 : 4	0.860	0.750	0.698
0.50	1 : 2	0.856	0.749	0.687
0.50	1 : 3	0.821	0.690	0.628
0.50	1 : 4	0.809	0.668	0.612
0.60	1 : 2	0.810	0.664	0.599
0.60	1 : 3	0.769	0.610	0.542
0.60	1 : 4	0.757	0.596	0.531

Table (A3.14): Comparison between Bending Moment Ratios

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		h_{em}	$(h_{em}/Hw)^{1/3}$	h_{em}	$(h_{em}/Hw)^{1/3}$	H_{em}	$(h_{em}/Hw)^{1/3}$
0.20	1 : 2	0.34	0.486	0.42	0.438	0.63	0.448
0.2	1 : 3	0.45	0.531	0.64	0.503	0.83	0.492
0.20	1 :4	0.53	0.563	0.72	0.525	0.93	0.510
0.30	1 : 2	0.58	0.577	0.81	0.545	1.17	0.550
0.30	1 : 3	0.70	0.616	1.12	0.607	1.48	0.595
0.30	1 :4	0.79	0.642	1.25	0.631	1.78	0.633
0.40	1 : 2	0.80	0.644	1.29	0.636	1.79	0.635
0.40	1 : 3	1.02	0.698	1.64	0.689	2.30	0.690
0.40	1 :4	1.06	0.707	1.77	0.708	2.59	0.718
0.50	1 : 2	1.08	0.711	1.78	0.708	2.59	0.718
0.50	1 : 3	1.26	0.749	2.14	0.754	3.12	0.764
0.50	1 :4	1.32	0.761	2.28	0.770	3.28	0.777
0.60	1 : 2	1.32	0.760	2.30	0.772	3.41	0.787
0.60	1 : 3	1.54	0.800	2.61	0.806	3.49	0.793
0.60	1 :4	1.60	0.811	2.69	0.813	3.55	0.797

Table (A3.15): Comparison between Equivalent Height Moment Ratios

2.2.2. Analysis of Deflection Results

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Db/D)^{1/4}$	Hw=5.00 $(Db/D)^{1/4}$	Hw=7.00 $(Db/D)^{1/4}$
0.20	1 : 2	0.970	0.942	0.944
0.20	1 : 3	0.938	0.911	0.921
0.20	1 : 4	0.913	0.892	0.900
0.30	1 : 2	0.924	0.886	0.886
0.30	1 : 3	0.879	0.841	0.847
0.30	1 : 4	0.848	0.808	0.794
0.40	1 : 2	0.872	0.820	0.816
0.40	1 : 3	0.796	0.754	0.742
0.40	1 : 4	0.755	0.712	0.695
0.50	1 : 2	0.804	0.745	0.721
0.50	1 : 3	0.712	0.655	0.634
0.50	1 : 4	0.653	0.577	0.587
0.60	1 : 2	0.726	0.641	0.632
0.60	1 : 3	0.597	0.503	0.507
0.60	1 : 4	0.499	0.449	0.453

Table (A3.16): Comparison between Deflection Ratios

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$
0.20	1 : 2	0.15	0.471	0.249	0.472	0.362	0.477
0.2	1 : 3	0.27	0.550	0.395	0.530	0.528	0.524
0.20	1 :4	0.36	0.589	0.494	0.561	0.679	0.558
0.30	1 : 2	0.32	0.572	0.523	0.569	0.780	0.578
0.30	1 : 3	0.47	0.630	0.780	0.628	1.082	0.627
03.0	1 :4	0.57	0.661	0.973	0.664	1.496	0.680
0.40	1 : 2	0.50	0.638	0.901	0.652	1.323	0.659
0.40	1 : 3	0.74	0.705	1.304	0.715	1.898	0.722
0.40	1 :4	0.88	0.735	1.550	0.746	2.261	0.754
0.50	1 : 2	0.71	0.698	1.363	0.723	2.059	0.736
0.50	1 : 3	1.05	0.768	1.850	0.780	2.821	0.797
0.50	1 :4	1.34	0.818	2.279	0.822	3.158	0.820
0.60	1 : 2	0.99	0.757	1.921	0.787	2.824	0.797
0.60	1 : 3	1.55	0.848	2.451	0.837	3.405	0.835
0.60	1 :4	1.69	0.866	2.752	0.861	3.905	0.864

Table (A3.17): Comparison between Equivalent Height Deflection Ratios

2.3. Analysis of Wall Group No. (1) with Different Top Berm Widths

2.3.1. Analysis of Bending Moment Results

Berm to wall height Ratio (Hb/Hw)	Slope .m	Bt=0.00 $(Mb/M)^{1/3}$	Bt=1.00 $(Mb/M)^{1/3}$	Bt=1.50 $(Mb/M)^{1/3}$	Bt=3.00 $(Mb/M)^{1/3}$
0.20	1 : 2	0.946	0.909	0.880	0.838
0.20	1 : 3	0.916	0.888	0.862	0.839
0.20	1 : 4	0.901	0.874	0.867	0.806
0.30	1 : 2	0.879	0.829	0.803	0.762
0.30	1 : 3	0.840	0.797	0.785	0.766
0.30	1 : 4	0.811	0.788	0.780	0.739
0.40	1 : 2	0.805	0.747	0.724	0.686
0.40	1 : 3	0.755	0.711	0.702	0.697
0.40	1 : 4	0.731	0.706	0.698	0.666
0.50	1 : 2	0.724	0.648	0.631	0.621
0.50	1 : 3	0.667	0.631	0.624	0.624
0.50	1 : 4	0.655	0.631	0.626	0.593
0.60	1 : 2	0.641	0.571	0.550	0.550
0.60	1 : 3	0.592	0.559	0.541	0.538
0.60	1 : 4	0.583	0.540	0.540	0.535

Table (A3.18): Comparison between bending Moment Ratios

2.3.2. Analysis of Deflection Results

Berm to wall height Ratio (Hb/Hw)	Slope .m	Bt=0.00 $(Db/D)^{1/4}$	Bt=1.00 $(Db/D)^{1/4}$	Bt=1.50 $(Db/D)^{1/4}$	Bt=3.00 $(Db/D)^{1/4}$
0.20	1 : 2	0.950	0.916	0.875	0.813
0.20	1 : 3	0.918	0.884	0.852	0.794
0.20	1 : 4	0.898	0.866	0.839	0.794
0.30	1 : 2	0.885	0.827	0.794	0.706
0.30	1 : 3	0.838	0.780	0.757	0.704
0.30	1 : 4	0.796	0.755	0.735	0.683
0.40	1 : 2	0.809	0.733	0.696	0.598
0.40	1 : 3	0.740	0.669	0.653	0.568
0.40	1 : 4	0.690	0.638	0.626	0.576
0.50	1 : 2	0.722	0.615	0.584	0.483
0.50	1 : 3	0.620	0.527	0.496	0.432
0.50	1 : 4	0.556	0.491	0.439	0.412
0.60	1 : 2	0.621	0.464	0.485	0.320
0.60	1 : 3	0.486	0.397	0.358	0.315
0.60	1 : 4	0.424	0.370	0.350	0.301

Table (A3.19): Comparison between Deflection Ratios

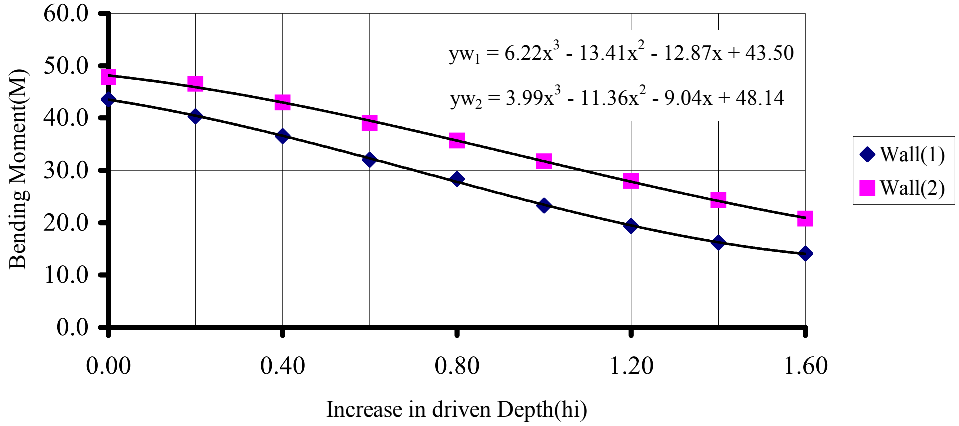

Figure (A3.1): Maximum Moment versus Increase in Driven Depth (Hw=3.00m & φ =32°)

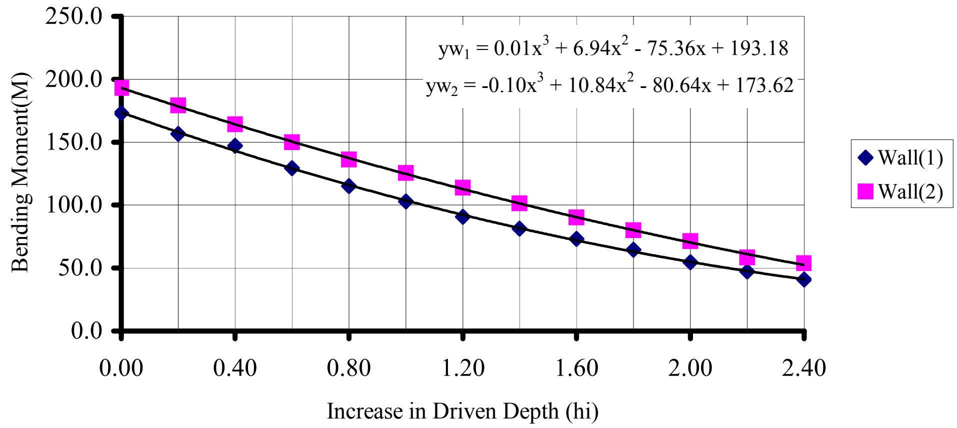

Figure (A3.2): Maximum Moment versus Increase in Driven Depth (Hw=5.00m & φ =32°)

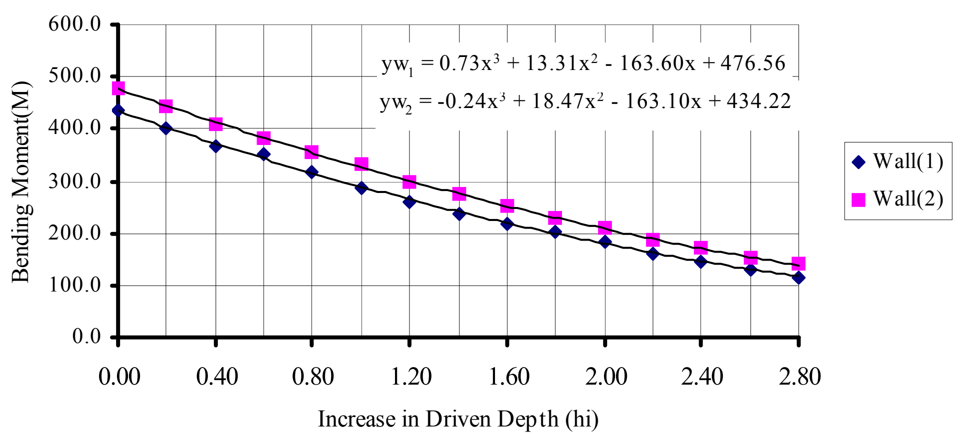

Figure (A3.3): Maximum Moment versus Increase in Driven Depth (Hw=7.00m & φ =32°)

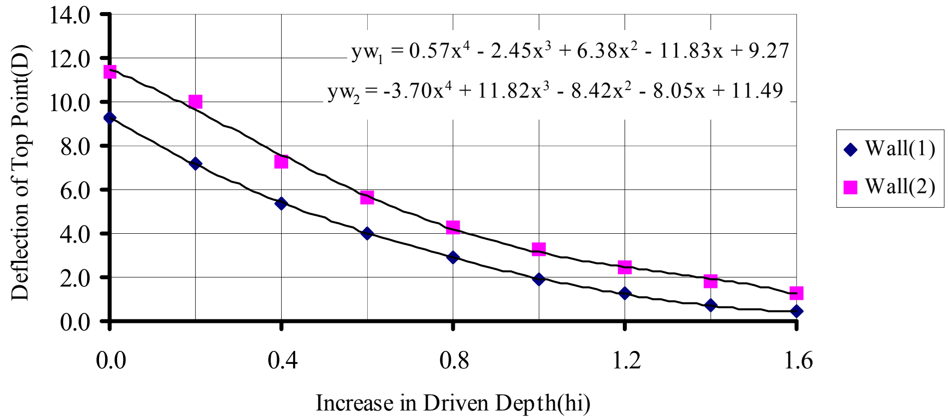

Figure (A3.4): The Deflection of the Wall versus Increase of Driven Depth (Hw=3.00m & φ =32°)

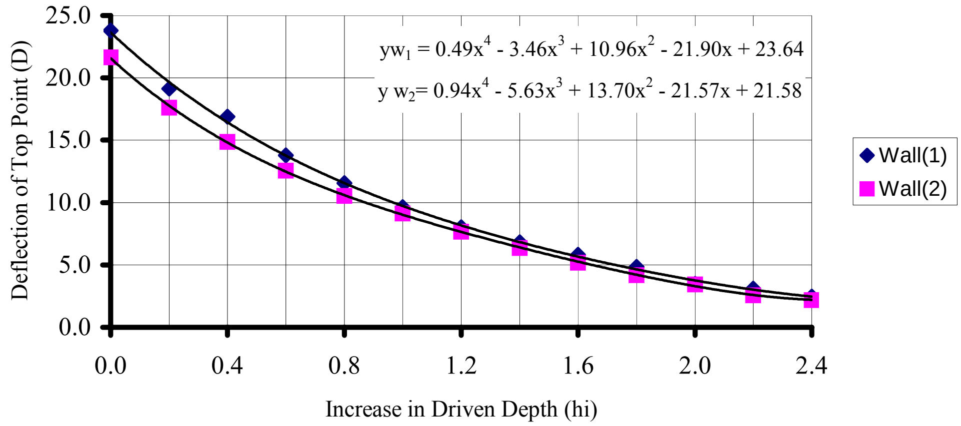

Figure (A3.5): The Deflection of the Wall versus Increase of Driven Depth (Hw=5.00m & φ =32°)

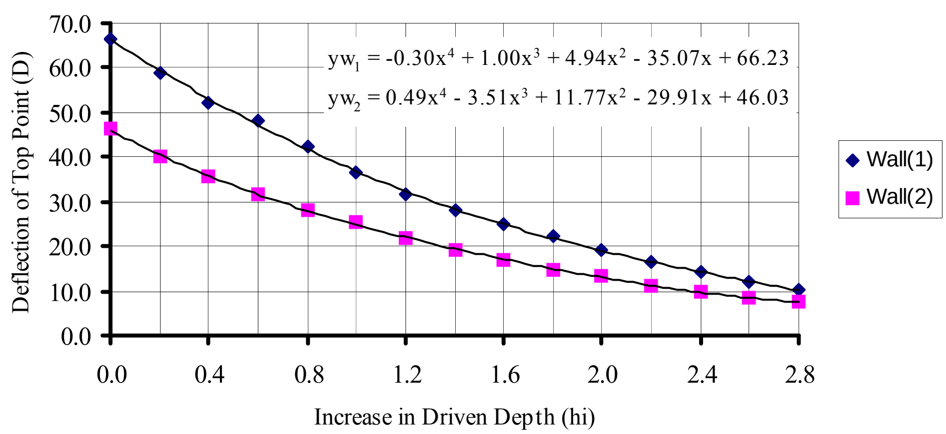

Figure (A3.6): The Deflection of the Wall versus Increase of Driven Depth (Hw=7.00m & φ =32°)

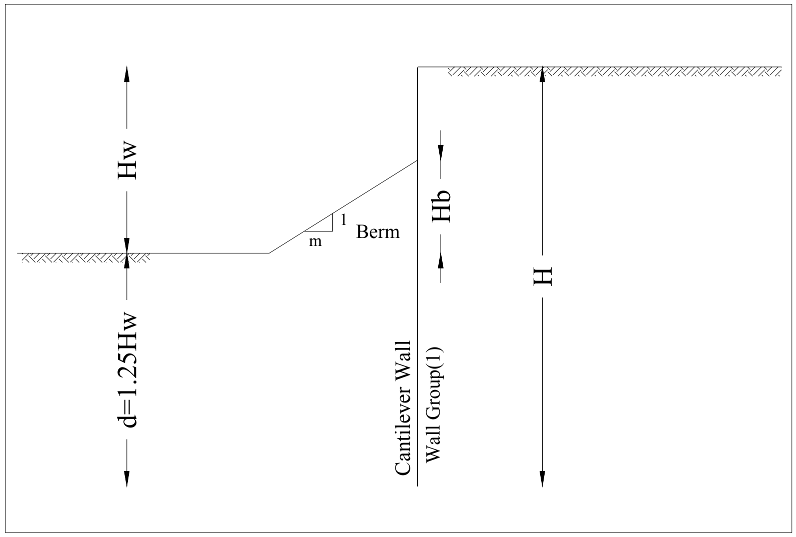

Figure (A3.7): Geometry of Bermed Wall with Zero Top Width

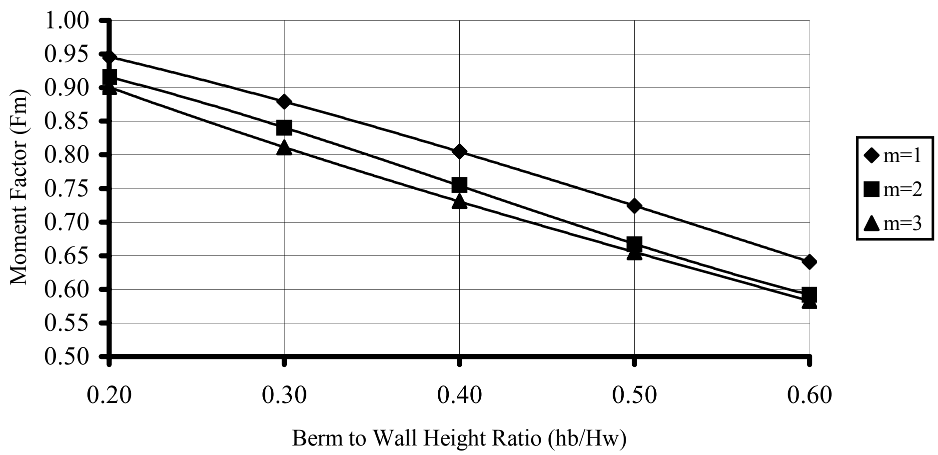

Figure (A3.8): Moment Factor versus Berm to Wall Height Ratio
(φ =32° & Wall Group No. (1))

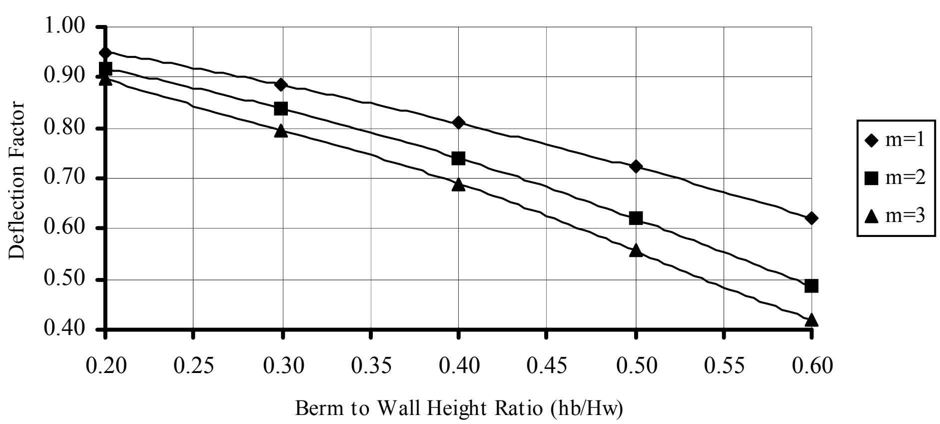

Figure (A3.9): Deflection Factor versus Berm to Wall Height Ratio
(φ =32° & Wall Group No. (1))

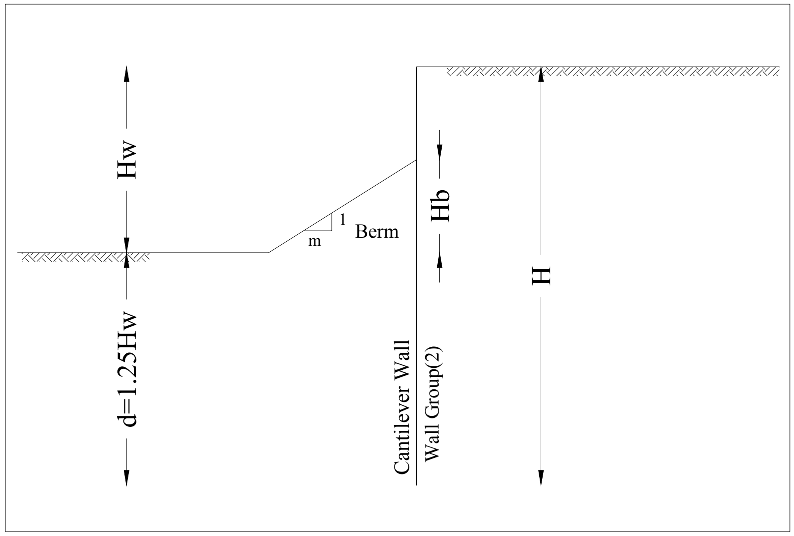

Figure (A3.10): Geometry of Bermed Wall with Zero Top Width

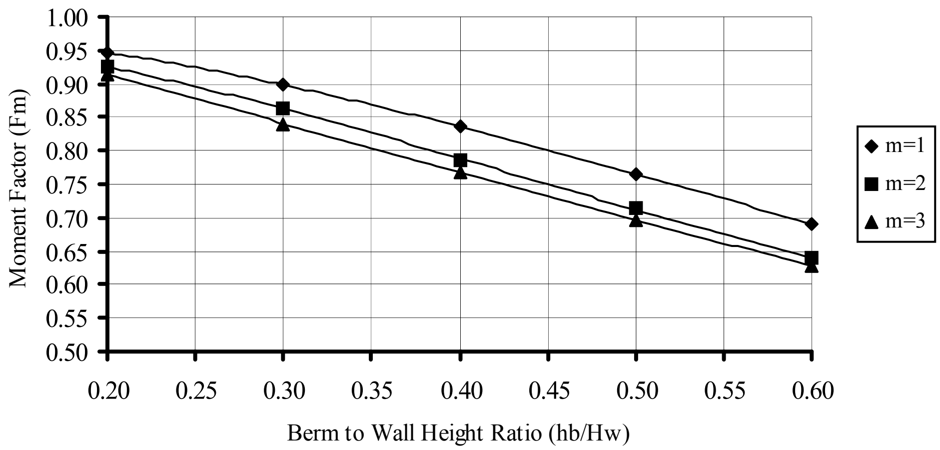

Figure (A3.11): Moment Factor versus Berm to Wall Height Ratio
(φ =32° & Wall Group No. (2))

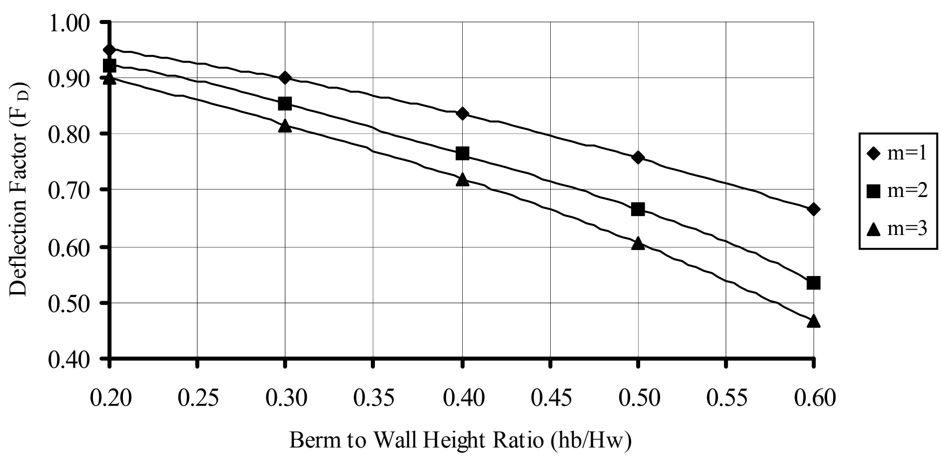

Figure (A3.12): Deflection Factor versus Berm to Wall Height Ratio
(φ =32° & Wall Group No. (2))

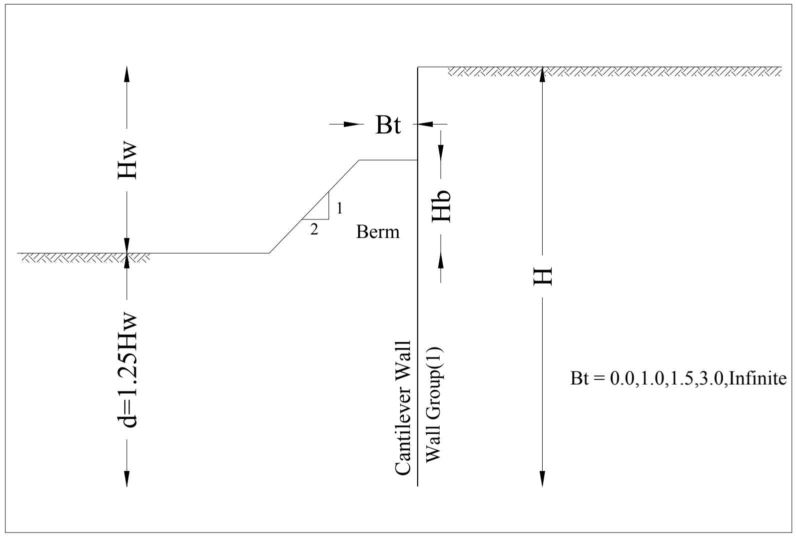

Figure (A3.13): Geometry of the Bermed Wall with Different Top Berm Widths

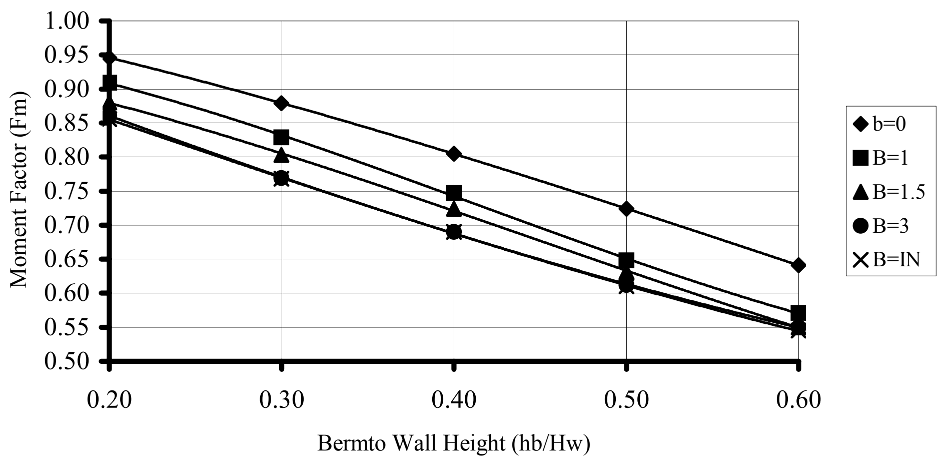

Figure (A3.14): Moment Factor versus Berm to Wall Height Ratio
(φ =32° & Wall Group No. (1))

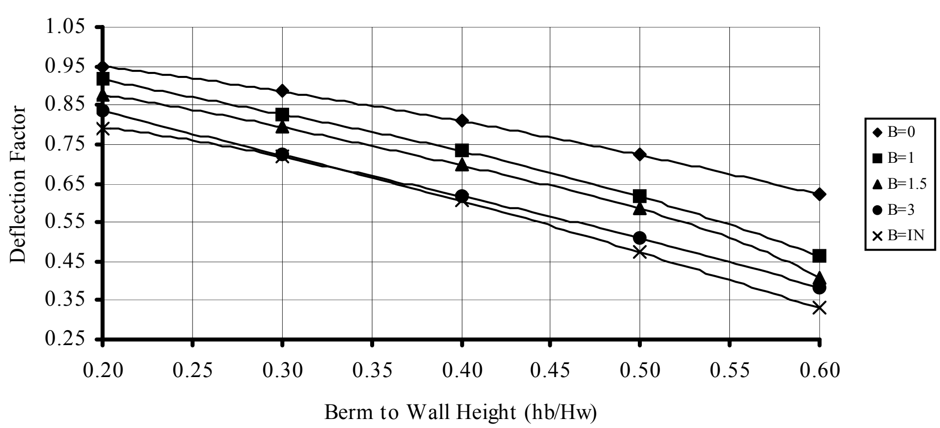

Figure (A3.15): Deflection Factor versus Berm to Wall Height Ratio
(φ =32° & Wall Group No. (1))

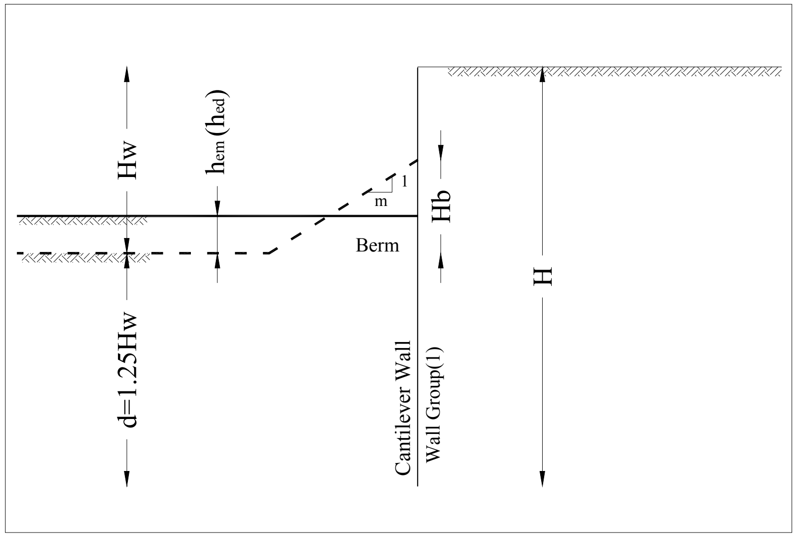

Figure (A3.16): Geometry of the Bermed Wall with Zero Top Width

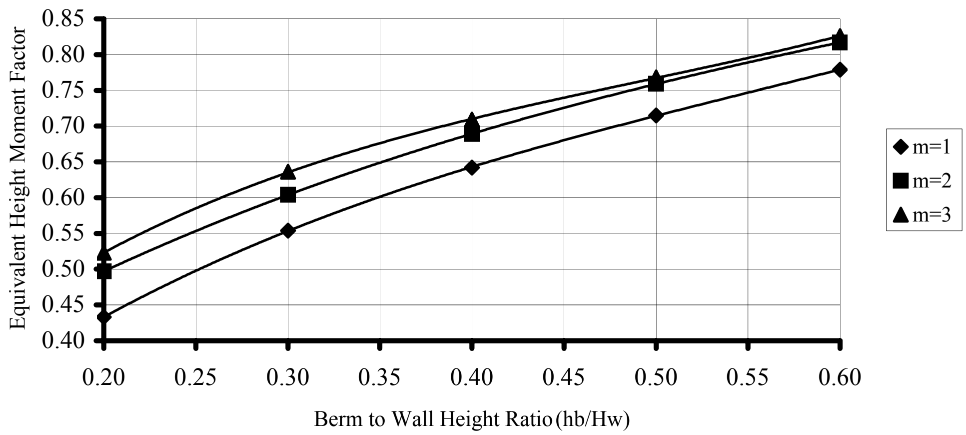

Figure (A3.17): Equivalent Height Moment Factor versus Wall to Berm Height Ratio (φ =32°&Wall Group (1))

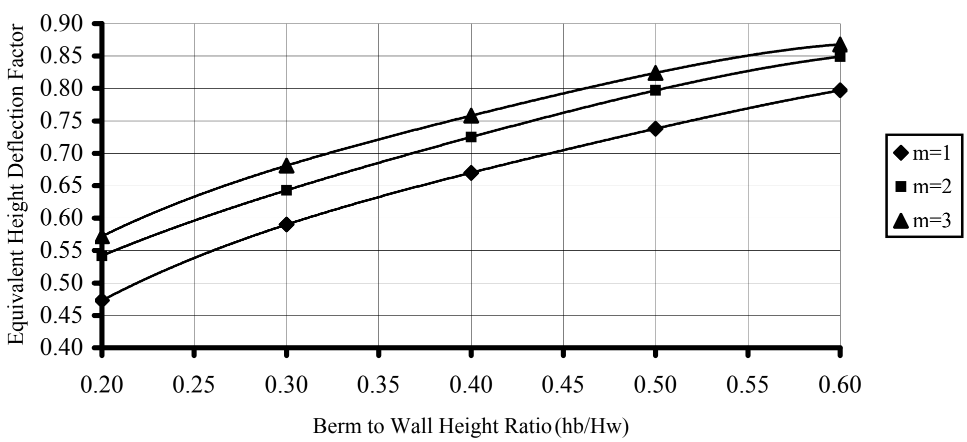

Figure (A3.18): Equivalent Height Deflection Factor versus Wall to Berm Height Ratio (φ =32°&Wall Group (1))

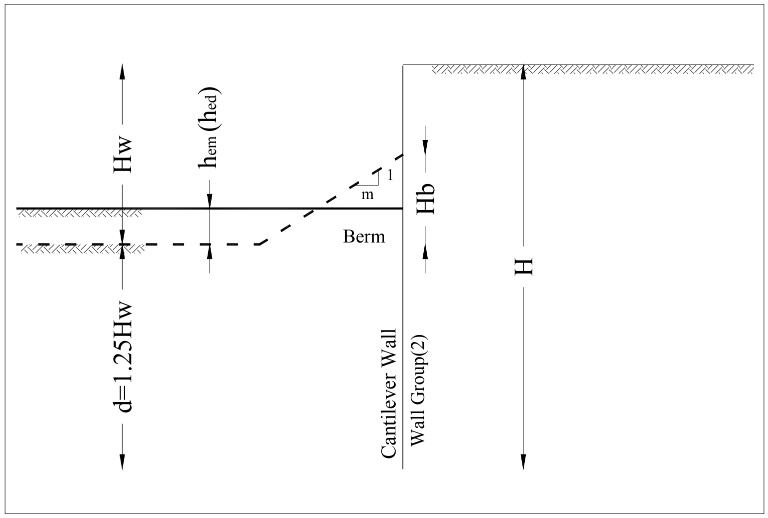

Figure (A3.19): Geometry of Bermed Wall with Zero Top Width

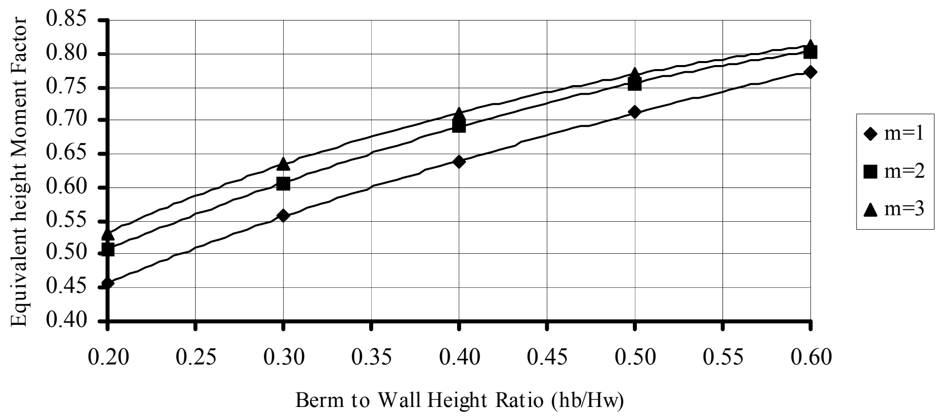

Figure (A3.20): Equivalent Height Moment Factor versus Wall to Berm Height Ratio (φ =32°&Wall Group (2))

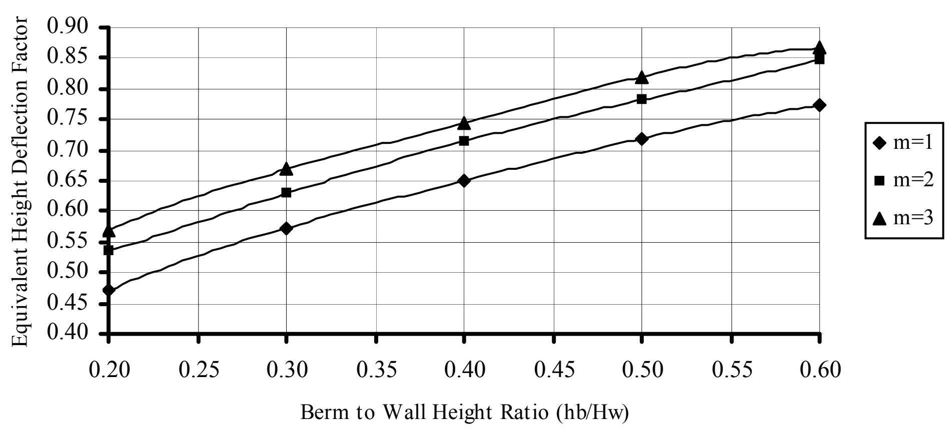

Figure (A3.21): Equivalent Height Deflection Factor versus Wall to Berm Height Ratio (φ =32°&Wall Group (2))

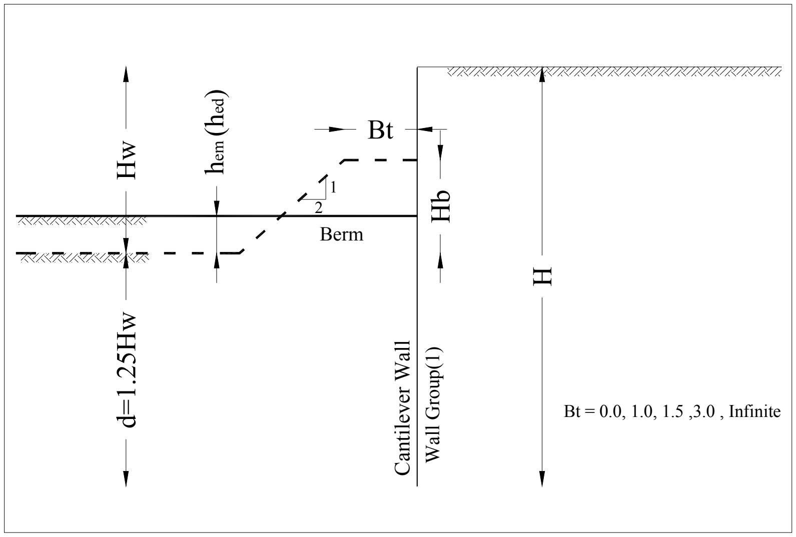

Figure (A3.22): Geometry of Bermed Wall with Different Top Berm Widths

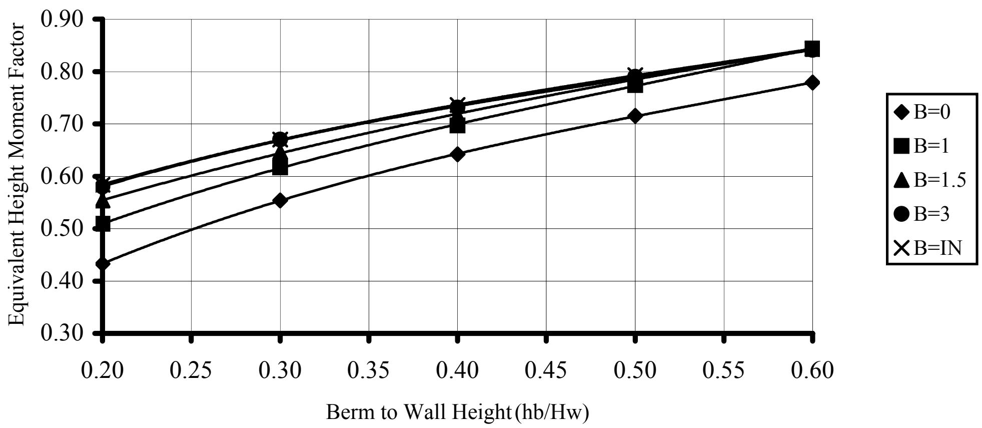

Figure (A3.23): Equivalent Height Moment Factor versus Wall to Berm Height Ratio
(φ =32° & Wall Group No. (1))

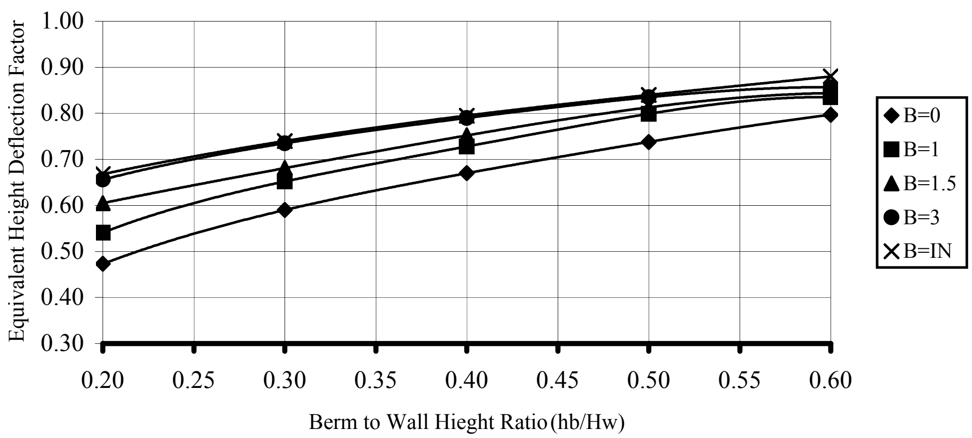

Figure (A3.24): Equivalent Height Deflection Factor versus Wall to Berm Height Ratio
(φ =32° & Wall Group No. (1))

APPENDIX (4)

RESULTS OF SOIL GROUP (4)

(φ=34°)

1. Numerical Results from Finite Element Analysis

1.1. Effect of Varying Driven Depth of the Wall

Increase in Driven depth (m)	Wall Group(1)		Wall Group(2)	
	Moment (KN.m/m’)	Deflection (mm)	Moment (KN.m/m’)	Deflection (mm)
0.00	42.750	7.900	46.560	9.650
0.20	37.910	5.610	44.020	7.580
0.40	33.620	4.120	40.030	5.510
0.60	29.210	2.930	36.800	4.290
0.80	25.310	2.110	33.240	3.280
1.00	21.870	1.540	29.380	2.560
1.20	18.090	0.929	26.170	1.920
1.40	15.420	0.597	22.440	1.370
1.60	12.990	0.383	19.300	1.030

Table (A4.1): Bending Moment and Deflection
3.0m Initial Free Height Wall

Increase in Driven depth (m)	Wall Group(1)		Wall Group(2)	
	Moment (kN.m/m’)	Deflection (mm)	Moment (kN.m/m’)	Deflection (mm)
0.00	156.540	18.880	169.830	15.930
0.20	143.220	15.880	160.140	13.830
0.40	129.960	13.550	148.840	11.830
0.60	116.660	11.410	135.400	10.000
0.80	101.090	9.190	122.610	8.450
1.00	94.240	8.160	112.450	7.220
1.20	82.970	6.740	99.690	5.980
1.40	71.350	5.500	87.970	4.780
1.60	62.260	4.470	77.120	3.850
1.80	54.490	3.680	74.980	3.390
2.00	47.740	3.020	62.570	2.670
2.20	41.300	2.420	54.190	2.110
2.40	35.680	1.930	47.160	1.690

Table (A4.2): Bending Moment and Deflection
5.0m Initial Free Height Wall

Increase in Driven depth (m)	Wall Group(1)		Wall Group(2)	
	Moment (kN.m/m')	Deflection (mm)	Moment (kN.m/m')	Deflection (mm)
0.00	392.190	56.210	407.780	35.240
0.20	353.110	48.480	395.730	32.570
0.40	334.830	44.330	357.220	28.060
0.60	302.180	38.720	332.330	25.060
0.80	279.920	34.570	310.320	22.620
1.00	258.900	30.920	285.640	19.990
1.20	231.960	26.510	263.660	17.690
1.40	213.200	23.420	238.640	15.430
1.60	191.980	20.480	219.960	13.650
1.80	181.190	18.530	198.920	11.930
2.00	159.090	15.520	179.090	10.260
2.20	143.520	13.390	168.310	9.320
2.40	128.740	11.480	152.790	8.130
2.60	115.540	9.850	135.370	6.880
2.80	104.730	8.510	122.570	5.950

Table (A4.3): Bending Moment and Deflection
7.0m Initial Free Height Wall

1.2. Results of Wall with Stabilizing Berm

1.2.1. Results of Wall with Zero Top Berm Width

Berm Height (m)	Berm Slope VL. To HL.	Wall Group No.(1)		Wall Group No.(2)	
		Moment (kN.m/m')	Deflection (mm)	Moment (kN.m/m')	Deflection (mm)
0.60	1 : 2	35.68	5.690	42.54	8.290
0.60	1 : 3	33.58	5.110	40.64	7.350
0.60	1 : 4	32.26	4.280	39.94	5.961
0.90	1 : 2	30.55	4.210	38.02	6.510
0.90	1 : 3	27.38	3.330	34.88	5.190
0.90	1 : 4	26.56	2.820	34.61	4.420
1.20	1 : 2	25.56	3.050	32.70	4.770
1.20	1 : 3	22.04	1.950	29.78	3.500
1.20	1 : 4	21.23	1.500	29.66	2.730
1.50	1 : 2	20.57	1.830	28.07	3.430
1.50	1 : 3	17.30	0.736	24.97	2.130
1.50	1 : 4	16.83	0.416	25.12	1.530
1.80	1 : 2	15.94	0.700	23.51	2.170
1.80	1 : 3	14.24	0.400	20.74	0.888
1.80	1 : 4	12.99	0.370	20.11	0.417

Table (A4.4): Bending Moment and Deflection
3.0m Free Height Wall

Berm Height (m)	Berm Slope VL. To HL.	Wall group No.(1)		Wall group No.(2)	
		Moment (kN.m/m')	Deflection (mm)	Moment (kN.m/m')	Deflection (mm)
1.00	1 : 2	127.33	14.530	146.14	13.140
1.00	1 : 3	117.60	13.310	129.14	11.090
1.00	1 : 4	109.41	11.910	129.44	10.970
1.20	1 : 2	101.41	11.070	122.73	10.520
1.20	1 : 3	82.26	8.270	107.21	8.580
1.20	1 : 4	73.83	6.640	99.79	7.230
1.50	1 : 2	73.06	7.240	97.49	7.760
1.50	1 : 3	58.34	4.800	79.96	5.300
1.50	1 : 4	54.07	3.730	71.77	3.860
1.50	1 : 2	50.84	4.330	73.44	5.120
1.50	1 : 3	40.83	2.310	56.18	2.540
1.50	1 : 4	37.58	1.510	51.28	1.530
1.80	1 : 2	36.97	2.350	50.29	2.380
1.80	1 : 3	27.45	0.520	40.50	1.342
1.80	1 : 4	26.29	0.233	38.92	0.358

Table (A4.5): Bending Moment and Deflection
5.0m Free Height Wall

Berm Height (m)	Berm Slope VL. To HL.	Wall group No.(1)		Wall group No.(2)	
		Moment (kN.m/m')	Deflection (mm)	Moment (kN.m/m')	Deflection (mm)
1.40	1 : 2	292.06	40.480	352.78	30.940
1.40	1 : 3	263.21	35.550	312.67	26.690
1.40	1 : 4	249.49	33.030	286.65	22.930
2.10	1 : 2	227.90	30.530	270.58	22.560
2.10	1 : 3	191.73	24.300	235.49	18.750
2.10	1 : 4	186.94	22.060	195.50	13.590
2.80	1 : 2	157.81	19.970	196.58	15.480
2.80	1 : 3	134.11	14.830	148.92	9.880
2.80	1 : 4	114.11	10.750	145.14	8.330
3.50	1 : 2	102.11	11.620	137.72	9.650
3.50	1 : 3	79.15	6.280	99.42	4.780
3.50	1 : 4	75.43	4.940	94.27	3.740
4.20	1 : 2	61.88	5.400	82.58	4.390
4.20	1 : 3	50.48	1.877	65.17	1.454
4.20	1 : 4	48.72	1.366	62.89	1.015

Table (A4.6): Bending Moment and Deflection
7.0m Free Height Wall

1.2.2. Results of Wall with Different Top Berm Widths

Berm height (m)	Berm slope VL. To HL.	Moment (KN.m/m')			Deflection (mm)		
		Bt=1.0	Bt=1.5	Bt=3.0	Bt=1.0	Bt=1.5	Bt=3.0
0.60	1 : 2	32.65	27.81	28.62	5.210	3.390	2.810
0.60	1 : 3	30.73	29.10	28.38	4.830	3.720	2.630
0.60	1 : 4	31.29	29.33	28.33	4.220	3.540	2.540
0.90	1 : 2	25.88	23.05	23.80	3.320	2.000	1.530
0.90	1 : 3	24.99	22.91	24.69	3.050	1.730	1.440
0.90	1 : 4	24.72	23.26	23.69	2.511	1.630	1.330
1.20	1 : 2	19.70	18.70	19.73	1.675	0.976	0.593
1.20	1 : 3	18.60	18.71	20.38	0.971	0.635	0.575
1.20	1 : 4	18.95	18.78	20.49	1.215	0.633	0.528
1.50	1 : 2	14.44	14.21	16.12	0.562	0.233	-
1.50	1 : 3	14.37	15.46	16.60	-	-	-
1.50	1 : 4	14.85	15.50	15.99	-	-	-
1.80	1 : 2	10.26	11.27	11.84	-	-	-
1.80	1 : 3	10.46	11.79	12.07	-	-	-
1.80	1 : 4	10.87	12.03	12.13	-	-	-

Table (A4.7): Bending Moment and Deflection
3.0m Free Height Wall

Berm height (m)	Berm slope VL. To HL.	Moment (kN.m/m')			Deflection (mm)		
		Bt=1.0	Bt=1.5	Bt=3.0	Bt=1.0	Bt=1.5	Bt=3.0
1.00	1 : 2	109.40	100.95	87.47	9.240	9.101	8.640
1.00	1 : 3	103.56	91.09	85.05	8.530	8.230	7.710
1.00	1 : 4	99.15	88.94	85.95	7.910	7.851	7.750
1.50	1 : 2	83.44	73.86	62.96	6.720	7.120	6.025
1.50	1 : 3	74.95	66.23	63.72	5.510	5.490	4.830
1.50	1 : 4	73.90	66.30	64.09	5.21	5.124	4.370
2.00	1 : 2	59.55	48.94	46.21	4.450	3.820	2.720
2.00	1 : 3	52.76	47.34	46.42	3.240	3.000	2.280
2.00	1 : 4	51.40	47.24	48.45	2.810	2.660	2.390
2.50	1 : 2	38.54	33.12	32.87	2.510	2.030	0.868
2.50	1 : 3	35.27	33.29	30.73	1.570	1.099	0.421
2.50	1 : 4	35.31	34.85	31.44	1.330	1.031	0.559
3.00	1 : 2	23.88	21.96	23.78	1.230	0.397	-
3.00	1 : 3	23.71	23.99	24.27	0.490	-	-
3.00	1 : 4	24.43	24.45	24.93	0.404	-	-

Table (A4.8): Bending Moment and Deflection
5.0m Free Height Wall

Berm height (m)	Berm slope VL. To HL.	Moment (kN.m/m’)			Deflection (mm)		
		Bt=1.0	**Bt=1.5**	**Bt=3.0**	**Bt=1.0**	**Bt=1.5**	**Bt=3.0**
1.40	1 : 2	265.05	240.28	222.29	32.150	31.730	28.520
1.40	1 : 3	241.79	225.10	211.09	28.370	26.090	25.730
1.40	1 : 4	232.96	219.39	210.35	26.420	25.62	24.380
2.10	1 : 2	225.00	175.63	151.24	23.56	22.470	17.150
2.10	1 : 3	173.93	159.08	148.84	18.430	17.870	15.370
2.10	1 : 4	157.46	145.05	140.52	15.010	14.46	13.640
2.80	1 : 2	140.41	125.40	108.82	14.960	12.990	10.710
2.80	1 : 3	114.95	111.5	92.66	10.010	9.120	6.970
2.80	1 : 4	109.18	107.64	103.82	8.310	7.05	6.770
3.50	1 : 2	84.29	67.44	61.39	7.730	5.980	3.550
3.50	1 : 3	74.07	66.33	63.86	4.760	3.930	2.883
3.50	1 : 4	71.90	66.14	62.53	3.950	3.510	2.420
4.20	1 : 2	49.12	41.94	39.95	3.550	2.038	0.587
4.20	1 : 3	45.56	42.26	39.22	1.730	0.683	-
4.20	1 : 4	45.87	41.01	38.52	1.451	0.727	-

Table (A4.9): Bending Moment and Deflection
7.0m Free Height Wall

2. Disscusion and Analysis of Results

2.1. Analysis of Wall Group No. (1) with Zero Top Berm Width

2.1.1. Analysis of Bending Moment Results

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Mb/M)^{1/3}$	Hw=5.00 $(Mb/M)^{1/3}$	Hw=7.00 $(Mb/M)^{1/3}$
0.20	1 : 2	0.942	0.927	0.909
0.20	1 : 3	0.923	0.903	0.878
0.20	1 : 4	0.911	0.881	0.862
0.30	1 : 2	0.894	0.859	0.837
0.30	1 : 3	0.862	0.801	0.790
0.30	1 : 4	0.854	0.773	0.783
0.40	1 : 2	0.843	0.770	0.740
0.40	1 : 3	0.802	0.714	0.701
0.40	1 : 4	0.792	0.697	0.664
0.50	1 : 2	0.784	0.682	0.640
0.50	1 : 3	0.740	0.634	0.588
0.50	1 : 4	0.733	0.617	0.579
0.60	1 : 2	0.720	0.614	0.542
0.60	1 : 3	0.693	0.556	0.506
0.60	1 : 4	0.673	0.548	0.500

Table (A4.10): Comparison between Bending Moment Ratios

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		h_{em}	$(h_{em}/Hw)^{1/3}$	h_{em}	$(h_{em}/Hw)^{1/3}$	h_{em}	$(h_{em}/Hw)^{1/3}$
0.20	1 : 2	0.30	0.466	0.47	0.456	0.70	0.463
0.2	1 : 3	0.40	0.510	0.63	0.501	0.94	0.511
0.20	1 :4	0.46	0.535	0.76	0.534	1.06	0.533
0.30	1 : 2	0.54	0.564	0.90	0.564	1.26	0.564
0.30	1 : 3	0.69	0.614	1.25	0.630	1.63	0.615
03.0	1 :4	0.74	0.626	1.42	0.658	1.68	0.622
0.40	1 : 2	0.79	0.640	1.44	0.660	2.02	0.661
0.40	1 : 3	0.98	0.688	1.78	0.709	2.34	0.694
0.40	1 :4	1.02	0.699	1.89	0.724	2.63	0.722
0.50	1 : 2	1.06	0.707	1.99	0.735	2.83	0.739
0.50	1 : 3	1.27	0.750	2.32	0.774	3.23	0.773
0.50	1 :4	1.30	0.757	2.48	0.792	3.30	0.779
0.60	1 : 2	1.36	0.768	2.48	0.792	3.58	0.800
0.60	1 : 3	1.49	0.792	2.65	0.809	3.83	0.818
0.60	1 :4	1.60	0.810	2.70	0.814	3.87	0.821

Table (A4.11): Comparison between Equivalent Height Moment Ratios

2.1.2. Analysis of Deflection Results

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Db/D)^{1/4}$	Hw=5.00 $(Db/D)^{1/4}$	Hw=7.00 $(Db/D)^{1/4}$
0.20	1 : 2	0.921	0.937	0.923
0.20	1 : 3	0.897	0.916	0.893
0.20	1 : 4	0.858	0.891	0.877
0.30	1 : 2	0.855	0.875	0.860
0.30	1 : 3	0.806	0.814	0.812
0.30	1 : 4	0.773	0.770	0.793
0.40	1 : 2	0.788	0.787	0.773
0.40	1 : 3	0.705	0.710	0.718
0.40	1 : 4	0.660	0.667	0.662
0.50	1 : 2	0.694	0.692	0.675
0.50	1 : 3	0.553	0.591	0.579
0.50	1 : 4	0.479	0.532	0.545
0.60	1 : 2	0.546	0.594	0.558
0.60	1 : 3	0.474	0.407	0.428
0.60	1 : 4	0.465	0.333	0.396

Table (A4.12): Comparison between Deflection Ratios

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$
0.20	1 : 2	0.19	0.505	0.31	0.498	0.530	0.525
0.2	1 : 3	0.26	0.542	0.41	0.536	0.746	0.571
0.20	1 :4	0.37	0.592	0.54	0.573	0.867	0.593
0.30	1 : 2	0.38	0.596	0.63	0.595	0.996	0.614
0.30	1 : 3	0.53	0.647	0.96	0.661	1.359	0.664
03.0	1 :4	0.63	0.677	1.20	0.700	1.507	0.681
0.40	1 : 2	0.58	0.663	1.10	0.686	1.655	0.697
0.40	1 : 3	0.85	0.730	1.54	0.745	2.068	0.737
0.40	1 :4	1.00	0.759	1.78	0.773	2.484	0.772
0.50	1 : 2	0.89	0.738	1.64	0.757	2.384	0.764
0.50	1 : 3	1.31	0.813	2.22	0.816	3.050	0.812
0.50	1 :4	1.54	0.847	2.65	0.853	3.421	0.836
0.60	1 : 2	1.51	0.842	2.20	0.815	3.310	0.829
0.60	1 : 3	1.70	0.868	2.93	0.875	4.052	0.872
0.60	1 :4	1.64	0.860	2.96	0.877	4.125	0.876

Table (A4.13): Comparison between Equivalent Height Deflection Ratios

2.2. Analysis of Wall Group No. (2) with Zero Top Berm Width

2.2.1. Analysis of Bending Moment Results

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Mb/M)^{1/3}$	Hw=5.00 $(Mb/M)^{1/3}$	Hw=7.00 $(Mb/M)^{1/3}$
0.20	1 : 2	0.969	0.949	0.949
0.20	1 : 3	0.955	0.910	0.911
0.20	1 : 4	0.949	0.911	0.885
0.30	1 : 2	0.934	0.895	0.869
0.30	1 : 3	0.907	0.856	0.829
0.30	1 : 4	0.905	0.835	0.779
0.40	1 : 2	0.888	0.829	0.781
0.40	1 : 3	0.861	0.776	0.712
0.40	1 : 4	0.860	0.748	0.706
0.50	1 : 2	0.844	0.754	0.693
0.50	1 : 3	0.812	0.690	0.622
0.50	1 : 4	0.813	0.669	0.611
0.60	1 : 2	0.796	0.665	0.585
0.60	1 : 3	0.763	0.618	0.540
0.60	1 : 4	0.755	0.610	0.534

Table (A4.14): Comparison between Bending Moment Ratios

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		h_{em}	$(h_{em}/Hw)^{1/3}$	h_{em}	$(h_{em}/Hw)^{1/3}$	h_{em}	$(h_{em}/Hw)^{1/3}$
0.20	1 : 2	0.27	0.447	0.42	0.437	0.46	0.402
0.2	1 : 3	0.38	0.503	0.70	0.520	0.77	0.480
0.20	1 :4	0.42	0.520	0.70	0.518	0.99	0.521
0.30	1 : 2	0.53	0.562	0.81	0.545	1.13	0.544
0.30	1 : 3	0.71	0.617	1.08	0.600	1.45	0.591
0.30	1 :4	0.72	0.622	1.26	0.631	1.85	0.642
0.40	1 : 2	0.83	0.651	1.26	0.631	1.84	0.640
0.40	1 : 3	0.99	0.690	1.60	0.683	2.41	0.701
0.40	1 :4	0.99	0.692	1.77	0.707	2.46	0.706
0.50	1 : 2	1.08	0.712	1.73	0.702	2.57	0.716
0.50	1 : 3	1.26	0.748	2.15	0.755	3.12	0.764
0.50	1 :4	1.25	0.746	2.15	0.755	3.26	0.775
0.60	1 : 2	1.34	0.765	2.33	0.775	3.45	0.790
0.60	1 : 3	1.51	0.795	2.71	0.816	3.61	0.802
0.60	1 :4	1.55	0.802	2.80	0.825	3.81	0.817

Table (A4.15): Comparison between Equivalent Height Moment Ratios

2.2.2. Analysis of Deflection Results

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Db/D)^{1/4}$	Hw=5.00 $(Db/D)^{1/4}$	Hw=7.00 $(Db/D)^{1/4}$
0.20	1 : 2	0.962	0.953	0.966
0.20	1 : 3	0.933	0.913	0.931
0.20	1 : 4	0.885	0.911	0.897
0.30	1 : 2	0.905	0.901	0.893
0.30	1 : 3	0.855	0.857	0.853
0.30	1 : 4	0.822	0.821	0.787
0.40	1 : 2	0.837	0.835	0.813
0.40	1 : 3	0.775	0.759	0.726
0.40	1 : 4	0.728	0.701	0.696
0.50	1 : 2	0.771	0.753	0.722
0.50	1 : 3	0.685	0.632	0.606
0.50	1 : 4	0.630	0.557	0.570
0.60	1 : 2	0.688	0.622	0.593
0.60	1 : 3	0.550	0.539	0.450
0.60	1 : 4	0.455	0.387	0.411

Table (A4.16): Comparison between Deflection Ratios

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$
0.20	1 : 2	0.12	0.445	0.264	0.480	0.25	0.436
0.2	1 : 3	0.21	0.513	0.481	0.557	0.51	0.520
0.20	1 :4	0.36	0.589	0.495	0.561	0.77	0.576
0.30	1 : 2	0.30	0.561	0.546	0.575	0.80	0.581
0.30	1 : 3	0.46	0.626	0.788	0.630	1.10	0.629
03.0	1 :4	0.58	0.663	0.981	0.665	1.60	0.692
0.40	1 : 2	0.52	0.646	0.902	0.652	1.40	0.669
0.40	1 : 3	0.75	0.707	1.312	0.716	2.09	0.739
0.40	1 :4	0.93	0.747	1.634	0.756	2.35	0.761
0.50	1 : 2	0.76	0.711	1.348	0.721	2.13	0.742
0.50	1 : 3	1.12	0.782	2.040	0.799	3.03	0.811
0.50	1 :4	1.36	0.820	2.476	0.839	3.23	0.824
0.60	1 : 2	1.11	0.779	2.101	0.805	3.11	0.816
0.60	1 : 3	1.65	0.862	2.569	0.847	3.61	0.847
0.60	1 :4	1.71	0.869	2.895	0.872	3.67	0.851

Table (A4.17): Comparison between Equivalent Height Deflection Ratios

2.3. Analysis of Wall Group No. (1) with Different Top Berm Widths

2.3.1. Analysis of Bending Moment Results

Berm to wall height Ratio (Hb/Hw)	Slope .m	Bt=0.00 $(Mb/M)^{1/3}$	Bt=1.00 $(Mb/M)^{1/3}$	Bt=1.50 $(Mb/M)^{1/3}$	Bt=3.00 $(Mb/M)^{1/3}$
0.20	1 : 2	0.926	0.893	0.860	0.838
0.20	1 : 3	0.901	0.873	0.856	0.839
0.20	1 : 4	0.885	0.867	0.845	0.806
0.30	1 : 2	0.863	0.830	0.786	0.762
0.30	1 : 3	0.818	0.794	0.768	0.766
0.30	1 : 4	0.803	0.783	0.775	0.739
0.40	1 : 2	0.784	0.736	0.704	0.686
0.40	1 : 3	0.739	0.706	0.715	0.697
0.40	1 : 4	0.718	0.702	0.694	0.666
0.50	1 : 2	0.702	0.641	0.615	0.621
0.50	1 : 3	0.654	0.626	0.621	0.624
0.50	1 : 4	0.643	0.627	0.624	0.593
0.60	1 : 2	0.625	0.552	0.545	0.550
0.60	1 : 3	0.585	0.549	0.554	0.558
0.60	1 : 4	0.574	0.554	0.559	0.599

Table (A4.18): Comparison between bending Moment Ratios

2.3.2. Analysis of Deflection Results

Berm to wall height Ratio (Hb/Hw)	Slope .m	Bt=0.00 $(Db/D)^{1/4}$	Bt=1.00 $(Db/D)^{1/4}$	Bt=1.50 $(Db/D)^{1/4}$	Bt=3.00 $(Db/D)^{1/4}$
0.20	1 : 2	0.927	0.812	0.852	0.838
0.20	1 : 3	0.902	0.841	0.837	0.819
0.20	1 : 4	0.875	0.776	0.826	0.806
0.30	1 : 2	0.863	0.706	0.763	0.725
0.30	1 : 3	0.811	0.699	0.681	0.669
0.30	1 : 4	0.779	0.673	0.652	0.641
0.40	1 : 2	0.753	0.652	0.641	0.623
0.40	1 : 3	0.711	0.587	0.600	0.581
0.40	1 : 4	0.663	0.558	0.593	0.574
0.50	1 : 2	0.657	0.541	0.572	0.521
0.50	1 : 3	0.574	0.539	0.503	0.496
0.50	1 : 4	0.519	0.515	0.492	0.481
0.60	1 : 2	0.486	0.504	0.437	0.421
0.60	1 : 3	0.437	0.410	0.363	0.352
0.60	1 : 4	0.398	0.392	0.358	0.339

Table (A4.19): Comparison between Deflection Ratios

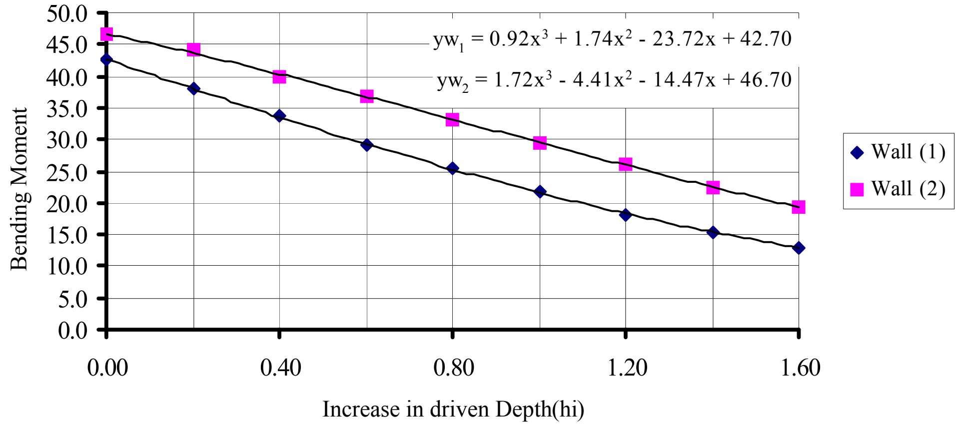

Figure (A4.1): Maximum Moment versus Increase in Driven Depth (Hw=3.00m & φ =34°)

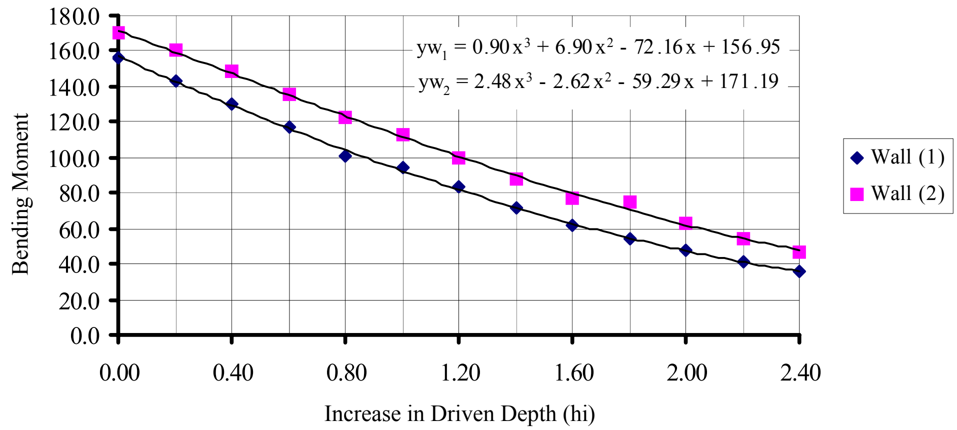

Figure (A4.2): Maximum Moment versus Increase in Driven Depth (Hw=5.00m & φ =34°)

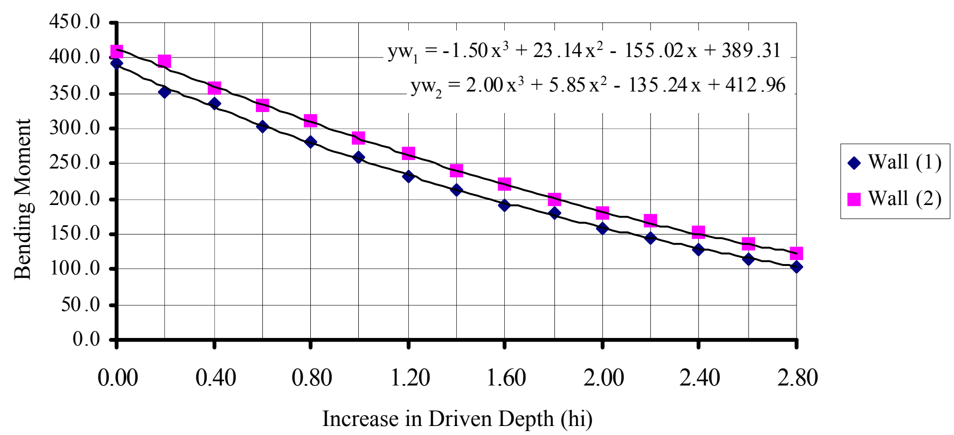

Figure (A4.3): Maximum Moment versus Increase in Driven Depth (Hw=7.00m & φ =34°)

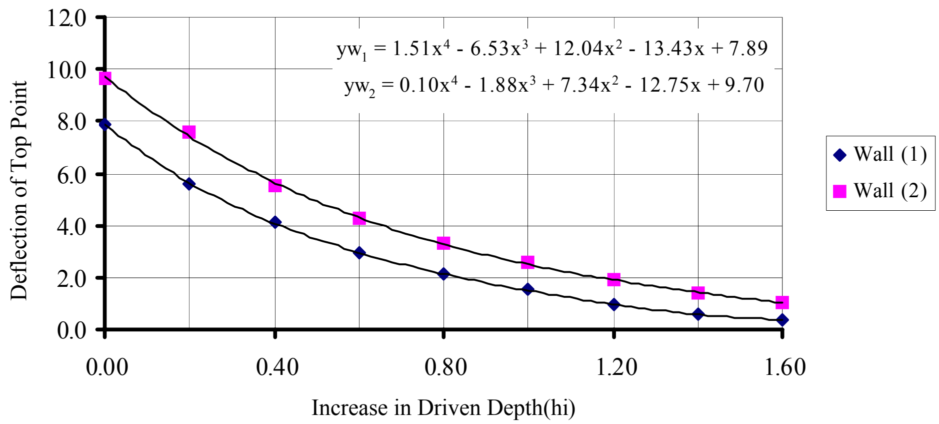

Figure (A4.4): The Deflection of the Wall versus Increase of Driven Depth (Hw=3.00m & φ =34°)

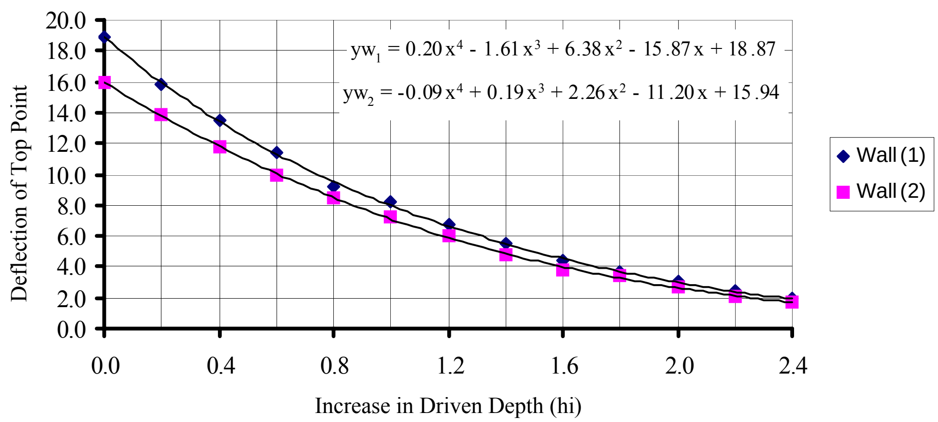

Figure (A4.5): The Deflection of the Wall versus Increase of Driven Depth (Hw=5.00m & φ =34°)

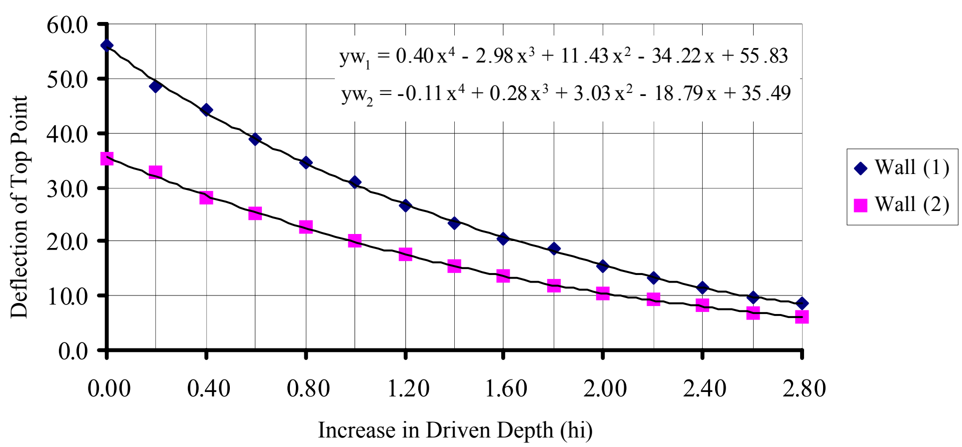

Figure (A4.6): The Deflection of the Wall versus Increase of Driven Depth (Hw=7.00m & φ =34°)

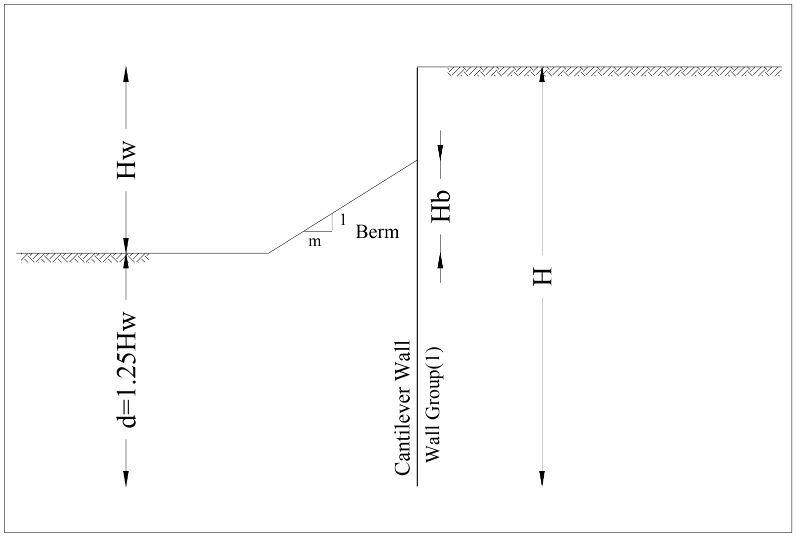

Figure (A4.7): Geometry of Bermed Wall with Zero Top Width

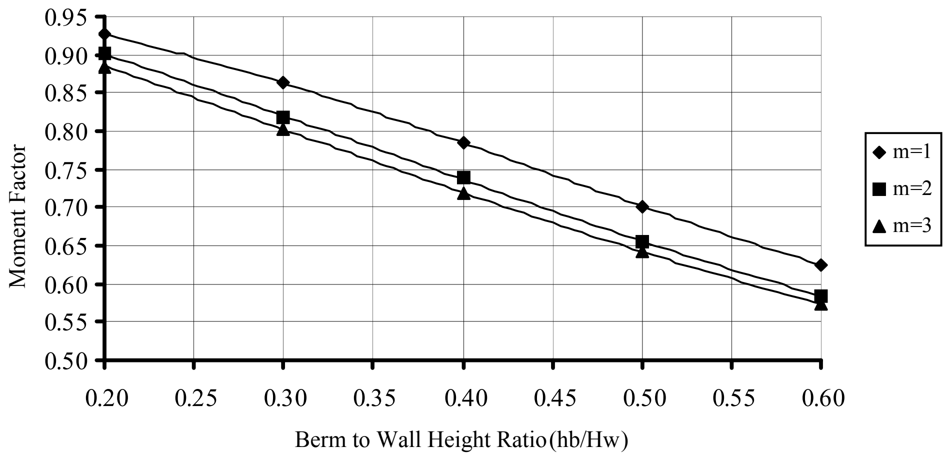

Figure (A4.8): Moment Factor versus Berm to Wall Height Ratio
(φ =34° & Wall Group No. (1))

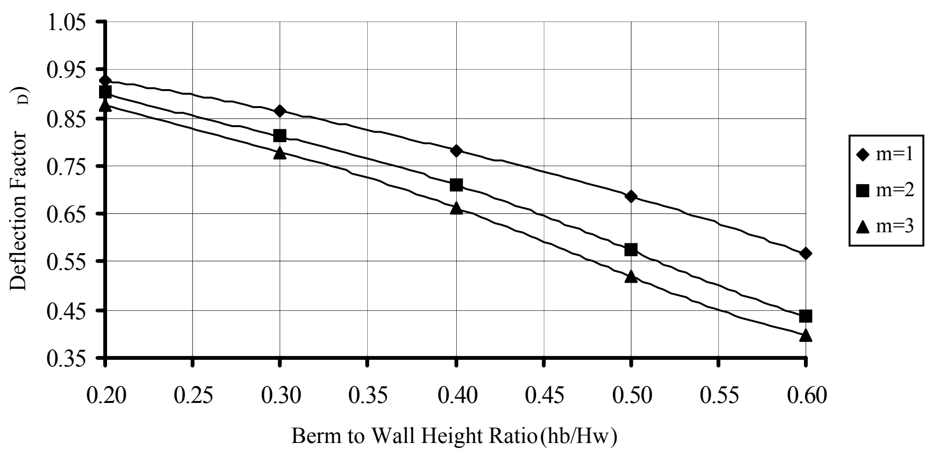

Figure (A4.9): Deflection Factor versus Berm to Wall Height Ratio
(φ =34° & Wall Group No. (1))

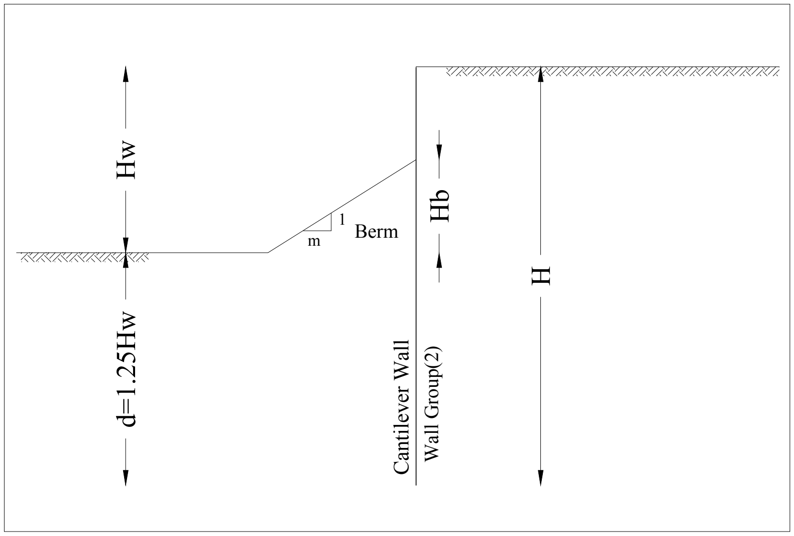

Figure (A4.10): Geometry of Bermed Wall with Zero Top Width

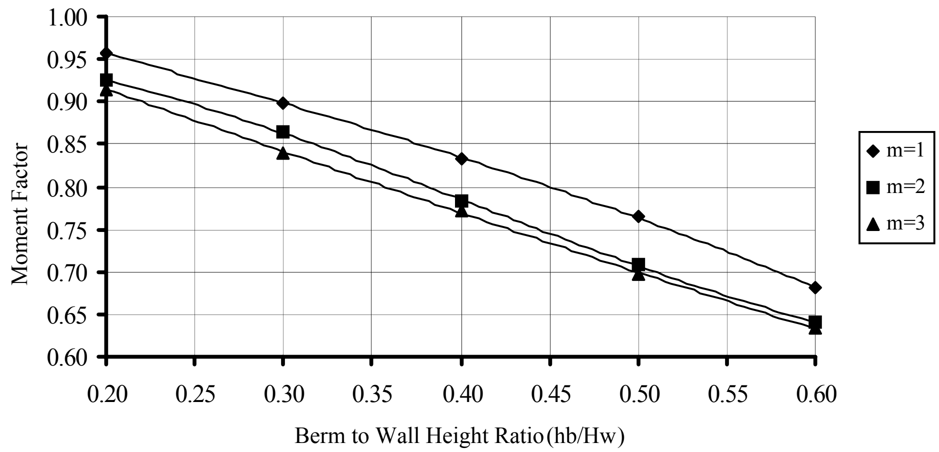

Figure (A4.11): Moment Factor versus Berm to Wall Height Ratio
(φ =34° & Wall Group No. (2))

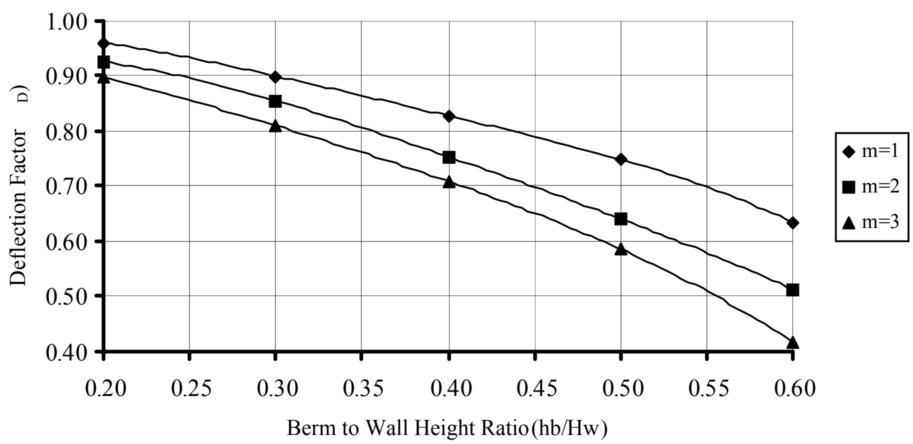

Figure (A4.12): Deflection Factor versus Berm to Wall Height Ratio
(φ =34° & Wall Group No. (2))

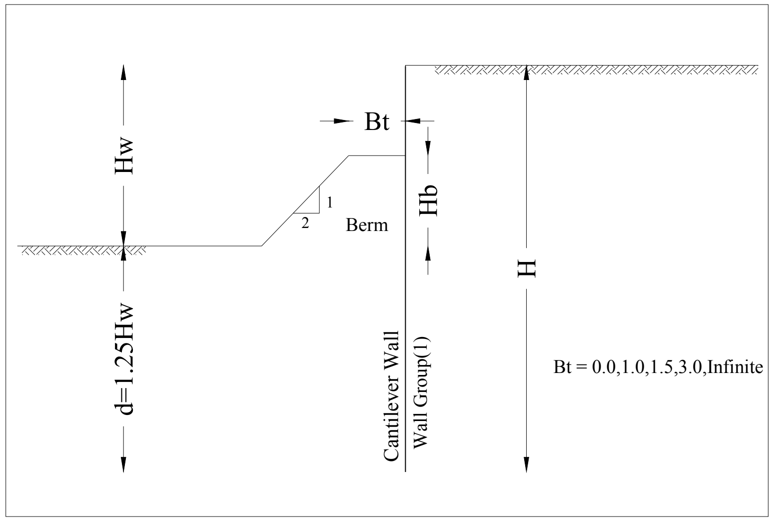

Figure (A4.13): Geometry of Bermed Wall with Different Top Berm Widths

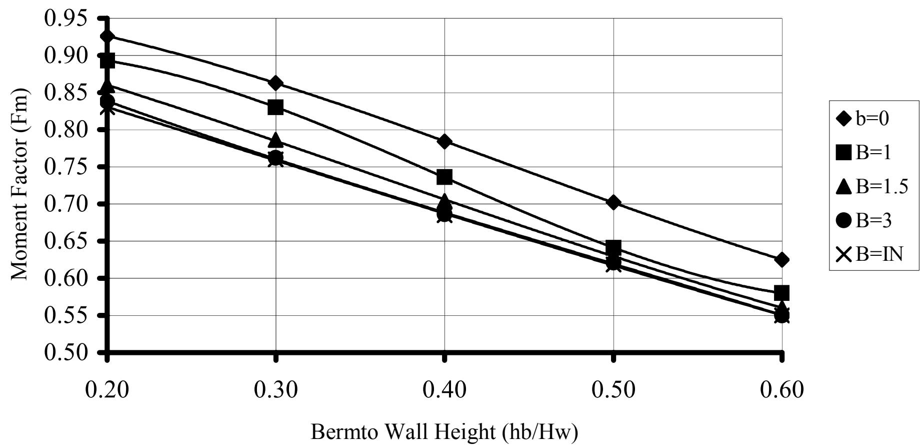

Figure (A4.14): Moment Factor versus Berm to Wall Height Ratio
(φ =34° & Wall Group No. (1))

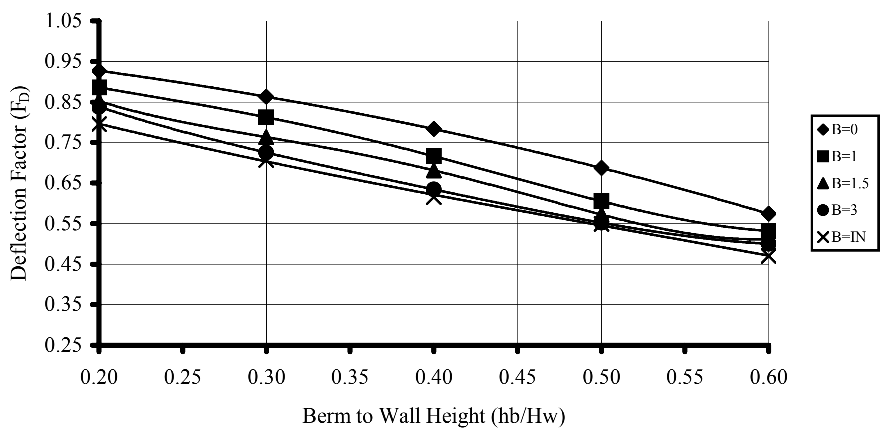

Figure (A4.15): Deflection Factor versus Berm to Wall Height Ratio
(φ =34° & Wall Group No. (1))

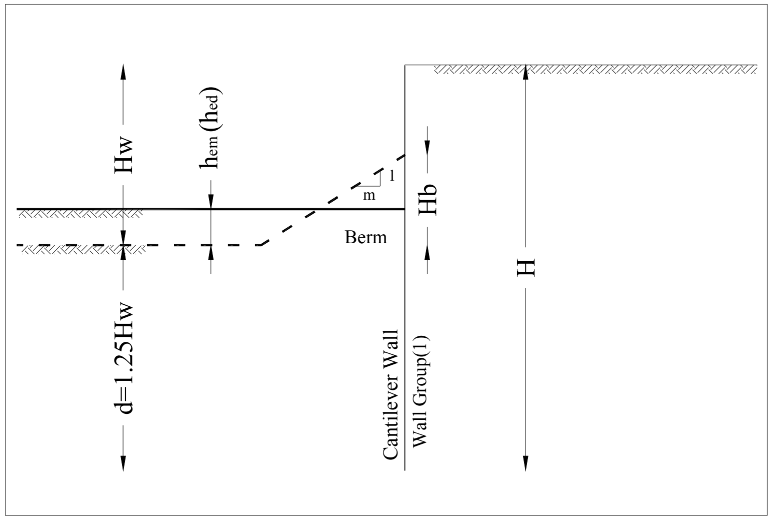

Figure (A4.16): Geometry of Bermed Wall with Zero Top Width

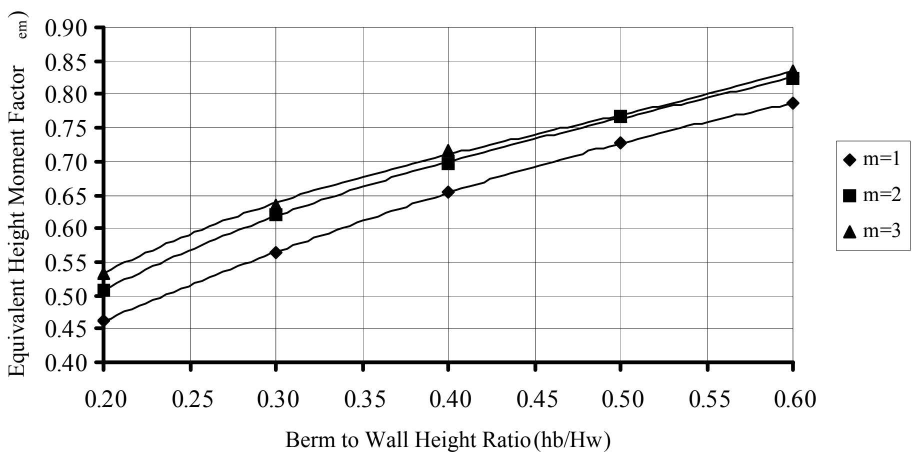

Figure (A4.17): Equivalent Height Moment Factor versus Wall to Berm Height Ratio (φ =34°&Wall Group (1))

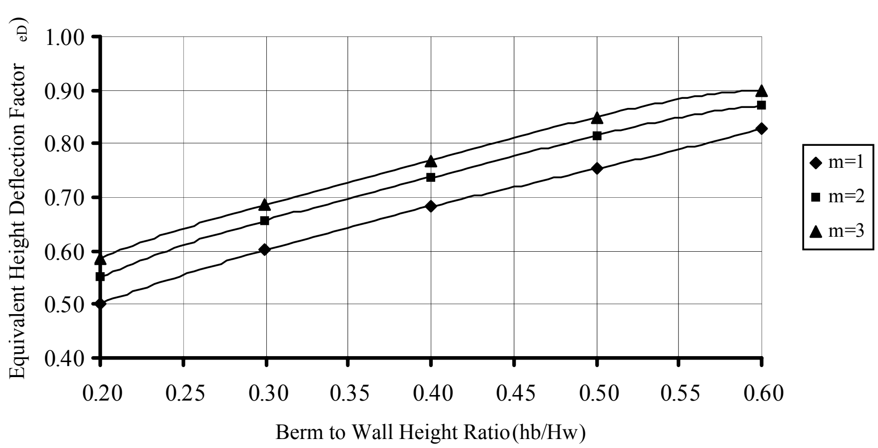

Figure (A4.18): Equivalent Height Deflection Factor versus Wall to Berm Height Ratio (φ =34°&Wall Group (1))

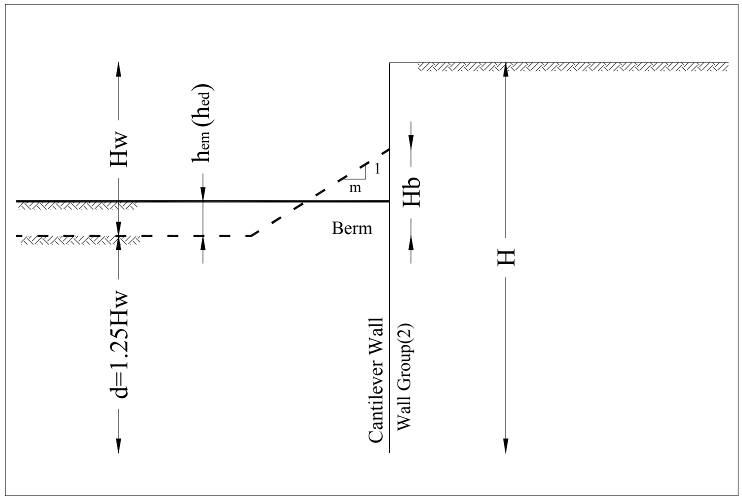

Figure (A4.19): Geometry of Bermed Wall with Zero Top Width

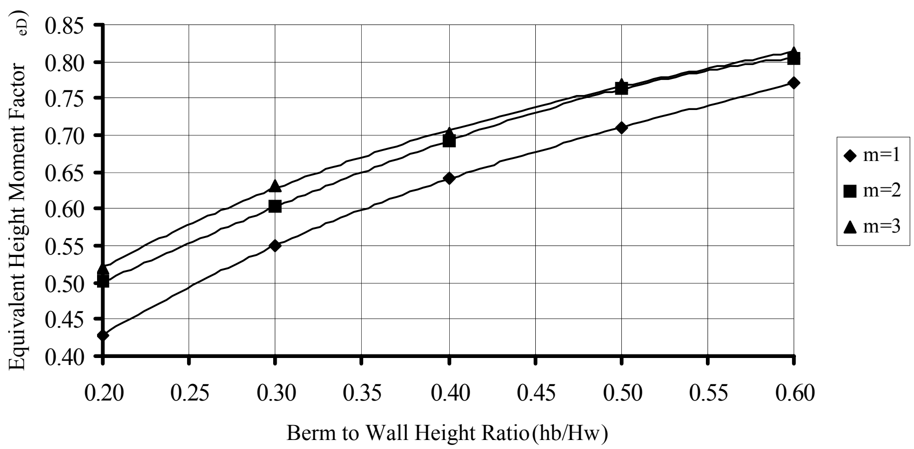

Figure (A4.20): Equivalent Height Moment Factor versus Wall to Berm Height Ratio
(φ =34°&Wall Group (2))

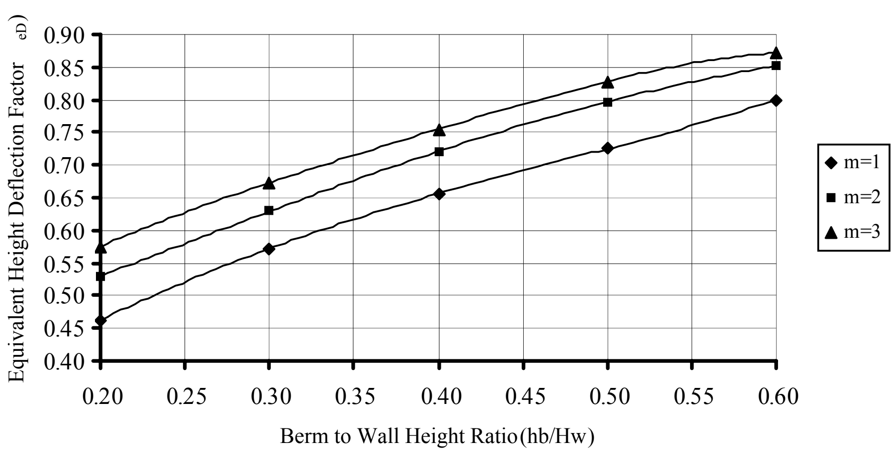

Figure (A4.21): Equivalent Height Deflection Factor versus Wall to Berm Height Ratio
(φ =34°&Wall Group (2))

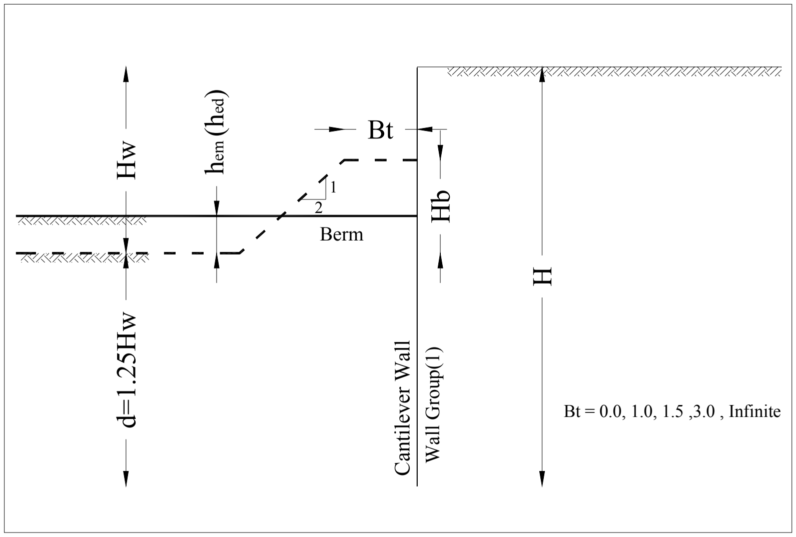

Figure (A4.22): Geometry of Bermed Wall with Different Top Berm Widths

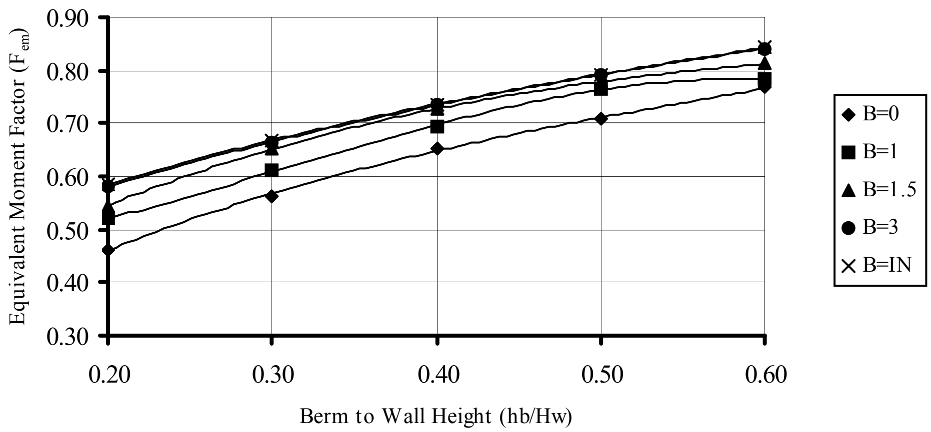

Figure (A4.23): Equivalent Height Moment Factor versus Wall to Berm Height Ratio
(φ =34° & Wall Group No. (1))

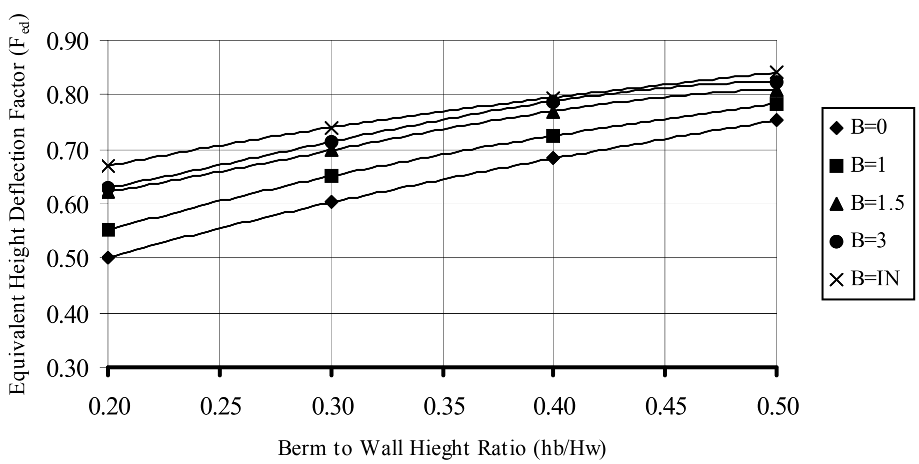

Figure (A4.24): Equivalent Height Deflection Factor versus Wall to Berm Height Ratio
(φ =34° & Wall Group No. (1))

APPENDIX (5)

RESULTS OF SOIL GROUP (5)

(φ=36°)

1. Numerical Results from Finite Element Analysis

1.1. Effect of Varying Driven Depth of the Wall

Increase in Driven depth (m)	Wall Group(1)		Wall Group(2)	
	Moment (KN.m/m')	Deflection (mm)	Moment (KN.m/m')	Deflection (mm)
0.00	39.250	4.580	45.120	5.290
0.20	37.280	3.650	44.780	4.170
0.40	35.130	3.040	41.300	3.480
0.60	30.560	2.250	36.620	2.540
0.80	26.920	1.640	33.250	1.900
1.00	23.440	1.250	29.660	1.440
1.20	20.810	0.987	25.810	1.080
1.40	16.720	0.641	22.540	0.791
1.60	14.070	0.454	19.440	0.586

Table (A5.1): Bending Moment and Deflection
3.0m Initial Free Height Wall

Increase in Driven depth (m)	Wall Group(1)		Wall Group(2)	
	Moment (kN.m/m')	Deflection (mm)	Moment (kN.m/m')	Deflection (mm)
0.00	145.700	14.990	168.250	11.250
0.20	136.300	13.280	160.570	10.580
0.40	125.080	11.630	154.920	9.600
0.60	114.200	10.040	140.290	8.140
0.80	102.250	8.630	129.310	7.040
1.00	93.250	7.490	117.380	6.050
1.20	84.530	6.520	107.420	5.240
1.40	75.920	5.551	97.450	4.520
1.60	67.720	4.710	88.360	3.870
1.80	60.360	3.980	76.470	3.150
2.00	53.220	3.330	68.620	2.670
2.20	46.660	2.750	60.630	2.250
2.40	40.640	2.250	53.780	1.870

Table (A5.2): Bending Moment and Deflection
5.0m Initial Free Height Wall

Increase in Driven depth (m)	Wall Group(1)		Wall Group(2)	
	Moment (kN.m/m')	Deflection (mm)	Moment (kN.m/m')	Deflection (mm)
0.00	330.210	44.120	392.120	24.190
0.20	322.430	41.940	352.680	21.020
0.40	298.280	37.460	330.360	18.870
0.60	282.660	34.750	304.360	16.880
0.80	254.100	29.870	280.620	14.980
1.00	233.150	26.550	257.090	13.220
1.20	215.940	23.710	239.870	11.900
1.40	196.900	20.770	222.020	10.590
1.60	181.110	18.570	199.180	9.190
1.80	168.090	16.450	187.530	8.300
2.00	153.310	14.420	169.100	7.180
2.20	139.290	12.570	157.260	6.440
2.40	125.700	10.860	142.870	5.630
2.60	115.820	9.590	128.150	4.830
2.80	105.050	8.320	116.160	4.200

Table (A5.3): Bending Moment and Deflection
7.0m Initial Free Height Wall

1.2. Results of Wall with Stabilizing Berm

1.2.1. Results of Wall with Zero Top Berm Width

Berm Height (m)	Berm Slope VL. To HL.	Wall Group No.(1)		Wall Group No.(2)	
		Moment (kN.m/m')	Deflection (mm)	Moment (kN.m/m')	Deflection (mm)
0.60	1 : 2	37.18	4.250	42.54	4.87
0.60	1 : 3	34.40	3.540	39.49	4.13
0.60	1 : 4	33.53	3.340	37.79	3.76
0.90	1 : 2	31.21	3.020	37.51	3.65
0.90	1 : 3	27.91	2.340	34.61	3.01
0.90	1 : 4	26.69	2.030	32.92	2.50
1.20	1 : 2	25.92	2.150	32.67	2.74
1.20	1 : 3	22.94	1.530	28.28	1.90
1.20	1 : 4	21.58	1.140	27.71	1.45
1.50	1 : 2	20.75	1.440	27.04	1.85
1.50	1 : 3	17.62	0.750	23.71	1.06
1.50	1 : 4	17.03	0.444	22.69	0.69
1.80	1 : 2	16.26	0.792	21.92	1.10
1.80	1 : 3	13.57	0.202	18.78	0.39
1.80	1 : 4	13.10	0.100	18.42	0.11

Table (A5.4): Bending Moment and Deflection
3.0m Free Height Wall

Berm Height (m)	Berm Slope VL. To HL.	Wall group No.(1)		Wall group No.(2)	
		Moment (kN.m/m’)	Deflection (mm)	Moment (kN.m/m’)	Deflection (mm)
1.00	1 : 2	122.90	12.470	139.99	9.43
1.00	1 : 3	107.52	10.670	120.00	8.86
1.00	1 : 4	101.08	9.780	116.14	8.82
1.20	1 : 2	94.25	9.250	117.90	7.60
1.20	1 : 3	83.25	7.860	94.92	6.79
1.20	1 : 4	75.91	6.760	89.29	5.75
1.50	1 : 2	71.85	6.840	94.70	5.81
1.50	1 : 3	59.77	5.140	68.75	3.82
1.50	1 : 4	55.75	4.300	66.36	3.20
1.50	1 : 2	52.19	4.740	72.09	4.16
1.50	1 : 3	42.42	3.160	51.30	1.94
1.50	1 : 4	40.52	2.460	48.72	1.40
1.80	1 : 2	35.73	3.000	52.13	2.82
1.80	1 : 3	28.58	1.520	37.84	0.41
1.80	1 : 4	27.86	1.050	37.50	0.19

Table (A5.5): Bending Moment and Deflection
5.0m Free Height Wall

Berm Height (m)	Berm Slope VL. To HL.	Wall group No.(1)		Wall group No.(2)	
		Moment (kN.m/m’)	Deflection (mm)	Moment (kN.m/m’)	Deflection (mm)
1.40	1 : 2	270.11	35.810	305.46	23.91
1.40	1 : 3	246.67	32.350	285.13	21.94
1.40	1 : 4	233.60	29.940	252.65	18.83
2.10	1 : 2	210.94	27.530	204.25	15.05
2.10	1 : 3	176.39	22.090	176.82	12.08
2.10	1 : 4	168.87	19.820	177.71	11.37
2.80	1 : 2	154.47	19.700	157.88	10.92
2.80	1 : 3	126.02	14.430	136.94	7.95
2.80	1 : 4	115.73	11.760	128.78	6.45
3.50	1 : 2	95.58	11.640	105.93	6.33
3.50	1 : 3	77.58	7.440	88.12	3.41
3.50	1 : 4	73.44	5.800	88.13	3.00
4.20	1 : 2	58.80	6.550	72.16	3.11
4.20	1 : 3	50.34	3.570	58.45	0.75
4.20	1 : 4	49.04	2.590	58.54	0.60

Table (A5.6): Bending Moment and Deflection
7.0m Free Height Wall

2. Disscusion and Analysis of Results

2.1. Analysis of Wall Group No. (1) with Zero Top Berm Width

2.1.1. Analysis of Bending Moment Results

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Mb/M)^{1/3}$	Hw=5.00 $(Mb/M)^{1/3}$	Hw=7.00 $(Mb/M)^{1/3}$
0.20	1 : 2	0.981	0.943	0.929
0.20	1 : 3	0.956	0.902	0.902
0.20	1 : 4	0.947	0.883	0.886
0.30	1 : 2	0.925	0.863	0.856
0.30	1 : 3	0.891	0.828	0.806
0.30	1 : 4	0.878	0.803	0.795
0.40	1 : 2	0.870	0.788	0.772
0.40	1 : 3	0.835	0.741	0.721
0.40	1 : 4	0.818	0.724	0.701
0.50	1 : 2	0.807	0.709	0.657
0.50	1 : 3	0.765	0.661	0.613
0.50	1 : 4	0.756	0.651	0.602
0.60	1 : 2	0.744	0.625	0.559
0.60	1 : 3	0.701	0.580	0.531
0.60	1 : 4	0.693	0.575	0.526

Table (A5.7): Comparison between Bending Moment Ratios

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		h_{em}	$(h_{em}/Hw)^{1/3}$	h_{em}	$(h_{em}/Hw)^{1/3}$	h_{em}	$(h_{em}/Hw)^{1/3}$
0.20	1 : 2	0.21	0.409	0.43	0.440	0.66	0.456
0.2	1 : 3	0.40	0.510	0.72	0.524	0.90	0.505
0.20	1 :4	0.46	0.537	0.85	0.554	1.04	0.529
0.30	1 : 2	0.59	0.581	0.99	0.583	1.28	0.567
0.30	1 : 3	0.77	0.636	1.23	0.626	1.67	0.620
03.0	1 :4	0.84	0.653	1.40	0.654	1.76	0.632
0.40	1 : 2	0.88	0.664	1.50	0.669	1.95	0.653
0.40	1 : 3	1.04	0.702	1.81	0.712	2.39	0.699
0.40	1 :4	1.11	0.719	1.92	0.727	2.59	0.718
0.50	1 : 2	1.16	0.729	2.02	0.740	3.41	0.787
0.50	1 : 3	1.35	0.766	2.35	0.777	3.45	0.790
0.50	1 :4	1.39	0.773	2.42	0.785	3.48	0.792
0.60	1 : 2	1.44	0.783	2.61	0.805	3.65	0.805
0.60	1 : 3	1.65	0.820	2.85	0.829	3.93	0.825
0.60	1 :4	1.70	0.828	2.95	0.839	4.10	0.837

Table (A5.8): Comparison between Equivalent Height Moment Ratios

2.1.2. Analysis of Deflection Results

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Db/D)^{1/4}$	Hw=5.00 $(Db/D)^{1/4}$	Hw=7.00 $(Db/D)^{1/4}$
0.20	1 : 2	0.983	0.954	0.948
0.20	1 : 3	0.939	0.918	0.924
0.20	1 : 4	0.925	0.898	0.906
0.30	1 : 2	0.902	0.886	0.887
0.30	1 : 3	0.846	0.850	0.840
0.30	1 : 4	0.817	0.819	0.817
0.40	1 : 2	0.829	0.821	0.816
0.40	1 : 3	0.761	0.765	0.755
0.40	1 : 4	0.707	0.731	0.717
0.50	1 : 2	0.750	0.749	0.716
0.50	1 : 3	0.637	0.677	0.640
0.50	1 : 4	0.559	0.636	0.601
0.60	1 : 2	0.646	0.668	0.620
0.60	1 : 3	0.459	0.564	0.532
0.60	1 : 4	0.385	0.514	0.491

Table (A5.9): Comparison between Deflection Ratios

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$
0.20	1 : 2	0.07	0.396	0.29	0.491	0.51	0.520
0.2	1 : 3	0.25	0.535	0.52	0.567	0.70	0.561
0.20	1 :4	0.30	0.561	0.64	0.599	0.83	0.586
0.30	1 : 2	0.38	0.596	0.72	0.616	0.96	0.609
0.30	1 : 3	0.57	0.662	0.94	0.659	1.31	0.657
03.0	1 :4	0.68	0.689	1.14	0.691	1.48	0.678
0.40	1 : 2	0.64	0.678	1.12	0.689	1.49	0.679
0.40	1 : 3	0.87	0.734	1.49	0.739	2.01	0.732
0.40	1 :4	1.07	0.772	1.71	0.765	2.35	0.761
0.50	1 : 2	0.91	0.742	1.59	0.751	2.37	0.763
0.50	1 : 3	1.35	0.818	2.07	0.802	2.80	0.795
0.50	1 :4	1.61	0.856	2.33	0.826	2.92	0.803
0.60	1 : 2	1.32	0.814	2.13	0.808	2.87	0.800
0.60	1 : 3	1.65	0.861	2.69	0.856	3.05	0.812
0.60	1 :4	1.72	0.870	2.85	0.869	3.10	0.816

Table (A5.10): Comparison between Equivalent Height Deflection Ratios

2.2. Analysis of Wall Group No. (2) with Zero Top Berm Width

2.2.1. Analysis of Bending Moment Results

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Mb/M)^{1/3}$	Hw=5.00 $(Mb/M)^{1/3}$	Hw=7.00 $(Mb/M)^{1/3}$
0.20	1 : 2	0.977	0.954	0.923
0.20	1 : 3	0.953	0.906	0.902
0.20	1 : 4	0.939	0.896	0.866
0.30	1 : 2	0.937	0.901	0.807
0.30	1 : 3	0.912	0.838	0.769
0.30	1 : 4	0.897	0.821	0.770
0.40	1 : 2	0.895	0.837	0.740
0.40	1 : 3	0.853	0.753	0.706
0.40	1 : 4	0.847	0.744	0.692
0.50	1 : 2	0.840	0.765	0.648
0.50	1 : 3	0.804	0.683	0.610
0.50	1 : 4	0.792	0.671	0.610
0.60	1 : 2	0.783	0.686	0.570
0.60	1 : 3	0.744	0.617	0.532
0.60	1 : 4	0.739	0.615	0.532

Table (A5.11): Comparison between Bending Moment Ratios

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		h_{em}	$(h_{em}/Hw)^{1/3}$	h_{em}	$(h_{em}/Hw)^{1/3}$	h_{em}	$(h_{em}/Hw)^{1/3}$
0.20	1 : 2	0.30	0.464	0.628	0.501	0.59	0.438
0.2	1 : 3	0.49	0.547	1.006	0.586	0.76	0.476
0.20	1 :4	0.58	0.579	1.074	0.599	1.05	0.532
0.30	1 : 2	0.60	0.584	1.043	0.593	1.58	0.608
0.30	1 : 3	0.75	0.629	1.444	0.661	1.92	0.650
0.30	1 :4	0.83	0.652	1.546	0.676	1.91	0.649
0.40	1 : 2	0.84	0.655	1.448	0.662	2.18	0.678
0.40	1 : 3	1.06	0.707	1.964	0.732	2.48	0.708
0.40	1 :4	1.09	0.713	2.023	0.740	2.60	0.719
0.50	1 : 2	1.12	0.721	1.887	0.723	2.94	0.749
0.50	1 : 3	1.31	0.758	2.716	0.816	3.20	0.770
0.50	1 :4	1.37	0.770	2.750	0.819	3.20	0.770
0.60	1 : 2	1.42	0.780	2.674	0.812	3.42	0.787
0.60	1 : 3	1.70	0.828	2.820	0.826	3.60	0.801
0.60	1 :4	1.76	0.837	2.940	0.838	3.60	0.801

Table (A5.12): Comparison between Equivalent Height Moment Ratios

2.2.2. Analysis of Deflection Results

Berm to wall height Ratio (Hb/Hw)	Berm slope .m	Hw=3.00 $(Db/D)^{1/4}$	Hw=5.00 $(Db/D)^{1/4}$	Hw=7.00 $(Db/D)^{1/4}$
0.20	1 : 2	0.981	0.963	0.998
0.20	1 : 3	0.941	0.948	0.977
0.20	1 : 4	0.919	0.947	0.941
0.30	1 : 2	0.912	0.912	0.889
0.30	1 : 3	0.870	0.887	0.842
0.30	1 : 4	0.830	0.851	0.829
0.40	1 : 2	0.849	0.853	0.821
0.40	1 : 3	0.775	0.768	0.758
0.40	1 : 4	0.724	0.735	0.720
0.50	1 : 2	0.770	0.785	0.716
0.50	1 : 3	0.670	0.648	0.614
0.50	1 : 4	0.602	0.598	0.594
0.60	1 : 2	0.676	0.712	0.600
0.60	1 : 3	0.521	0.440	0.420
0.60	1 : 4	0.383	0.363	0.398

Table (A5.13): Comparison between Deflection Ratios

Hb/Hw	.m	Hw=3.00m		Hw=5.00m		Hw=7.00m	
		(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$	(h_{ed})	$(h_{ed}/Hw)^{1/4}$
0.20	1 : 2	0.08	0.401	0.399	0.531	0.200	0.411
0.2	1 : 3	0.23	0.525	0.506	0.564	0.352	0.474
0.20	1 :4	0.31	0.566	0.513	0.566	0.403	0.490
0.30	1 : 2	0.33	0.577	0.730	0.618	0.785	0.579
0.30	1 : 3	0.48	0.634	0.876	0.647	1.165	0.639
03.0	1 :4	0.62	0.675	1.077	0.681	1.269	0.653
0.40	1 : 2	0.56	0.656	1.064	0.679	1.338	0.661
0.40	1 : 3	0.81	0.721	1.567	0.748	1.862	0.718
0.40	1 :4	0.99	0.759	1.803	0.775	2.182	0.747
0.50	1 : 2	0.83	0.725	1.460	0.735	2.210	0.750
0.50	1 : 3	1.20	0.796	2.350	0.828	3.227	0.824
0.50	1 :4	1.50	0.841	2.506	0.841	3.483	0.840
0.60	1 : 2	1.18	0.792	1.977	0.793	3.416	0.836
0.60	1 : 3	1.60	0.855	2.704	0.858	3.500	0.841
0.60	1 :4	1.71	0.868	2.739	0.860	3.812	0.859

Table (A5.14): Comparison between Equivalent Height Deflection Ratios

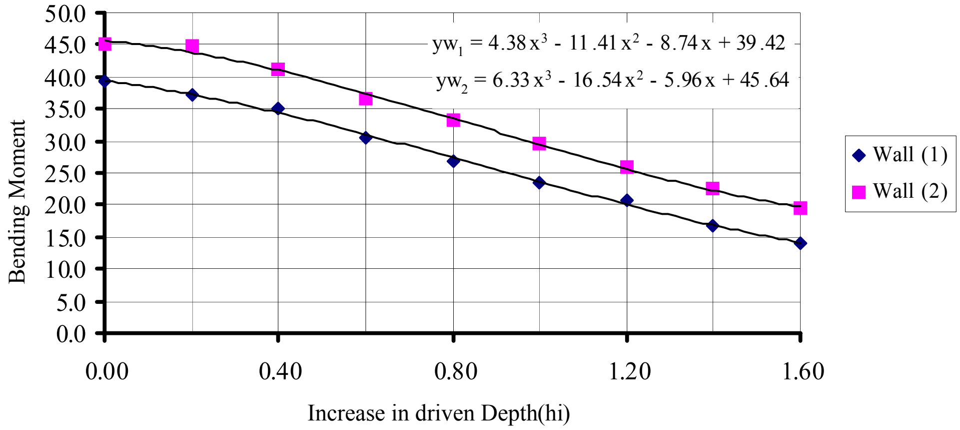

Figure (A5.1): Maximum Moment versus Increase in Driven Depth
(Hw=3.00m & φ =36°)

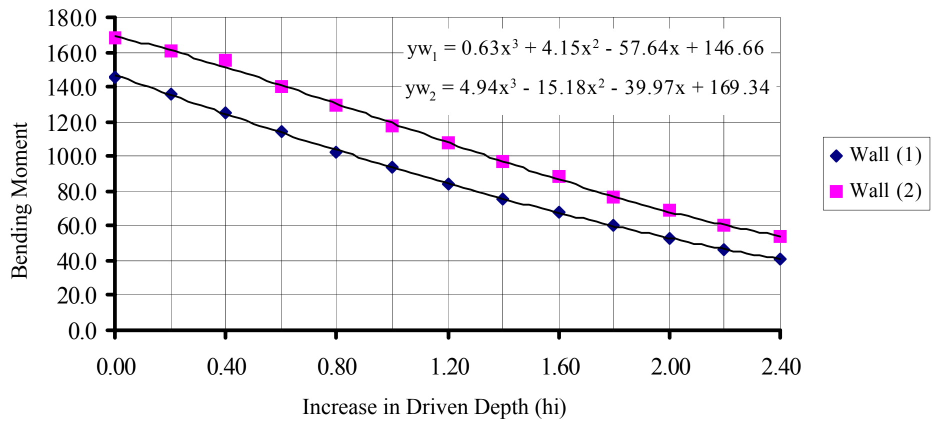

Figure (A5.2): Maximum Moment versus Increase in Driven Depth
(Hw=5.00m & φ =36°)

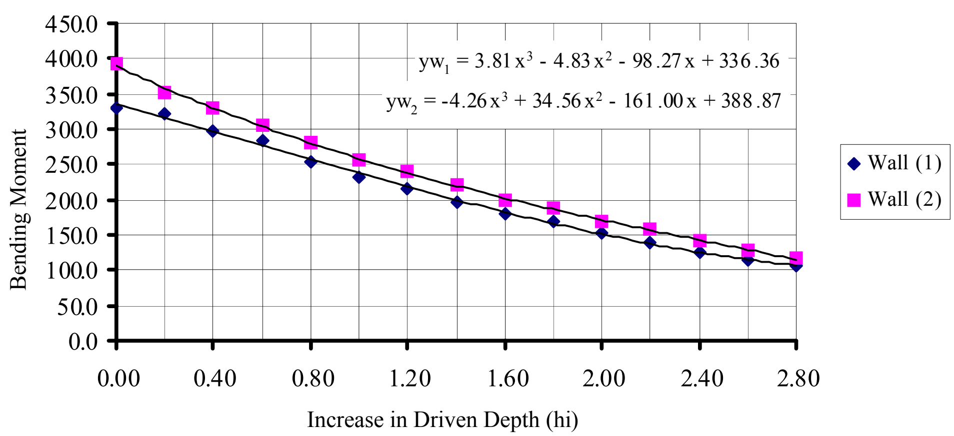

Figure (A5.3): Maximum Moment versus Increase in Driven Depth
(Hw=7.00m & φ =36°)

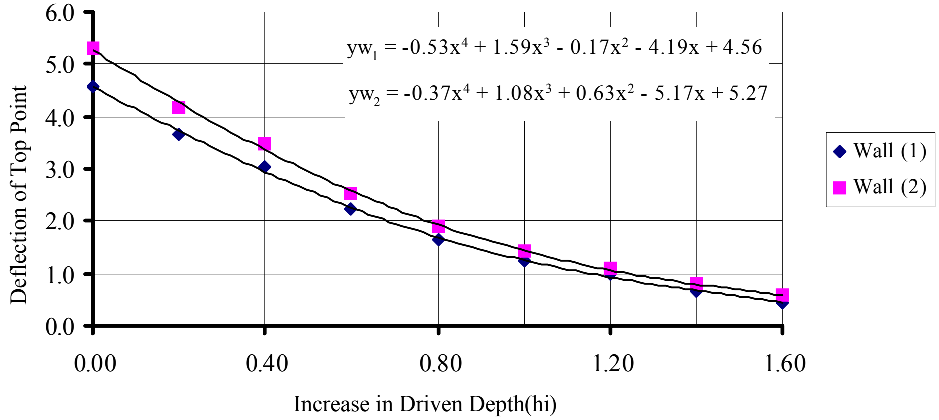

Figure (A5.4): The Deflection of the Wall versus Increase of Driven Depth (Hw=3.00m & φ =36°)

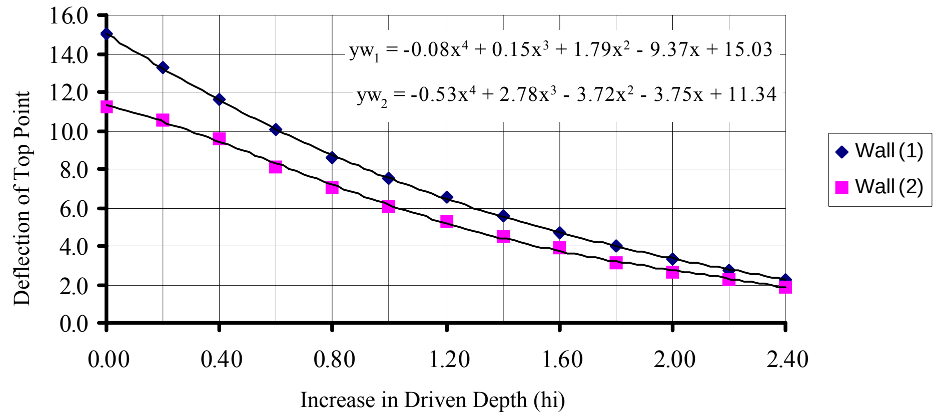

Figure (A5.5): The Deflection of the Wall versus Increase of Driven Depth (Hw=5.00m & φ =36°)

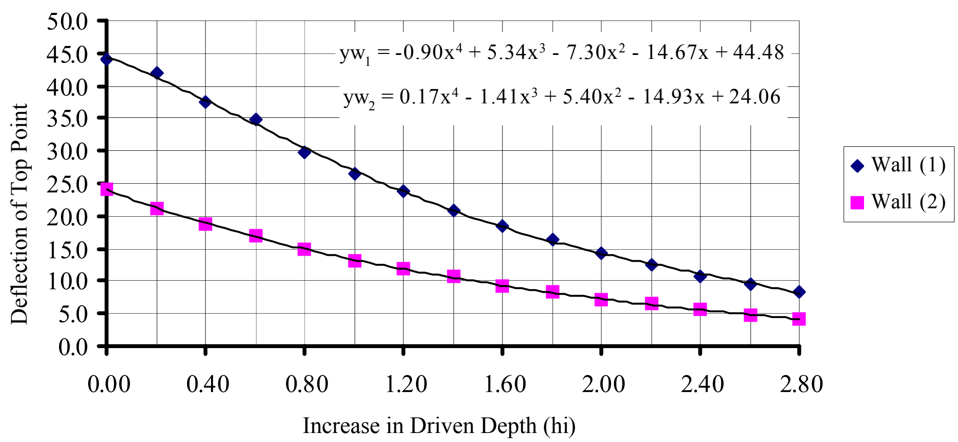

Figure (A5.6): The Deflection of the Wall versus Increase of Driven Depth (Hw=7.00m & φ =36°)

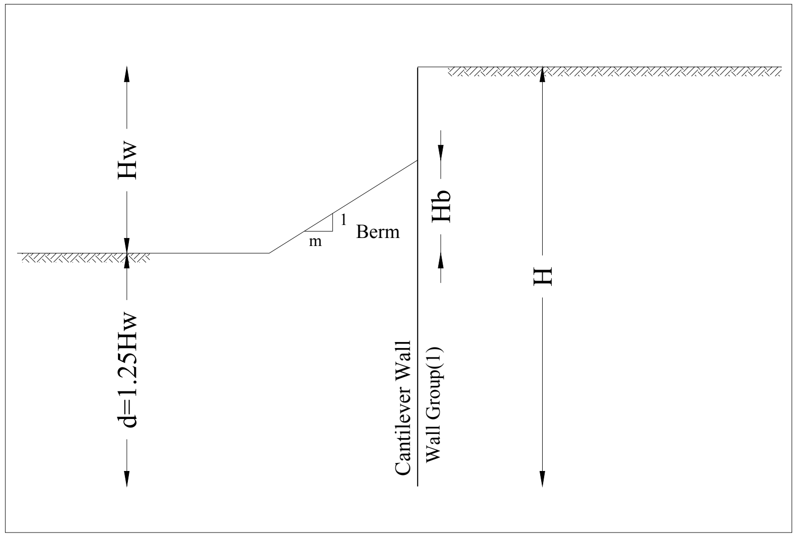

Figure (A5.7): Geometry of the Bermed Wall with Zero Top Width

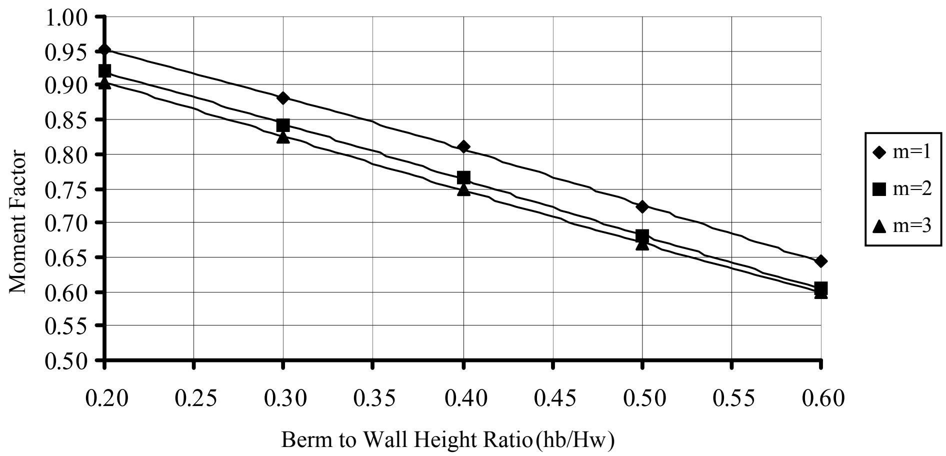

Figure (A5.8): Moment Factor versus Berm to Wall Height Ratio
(φ =36° & Wall Group No. (1))

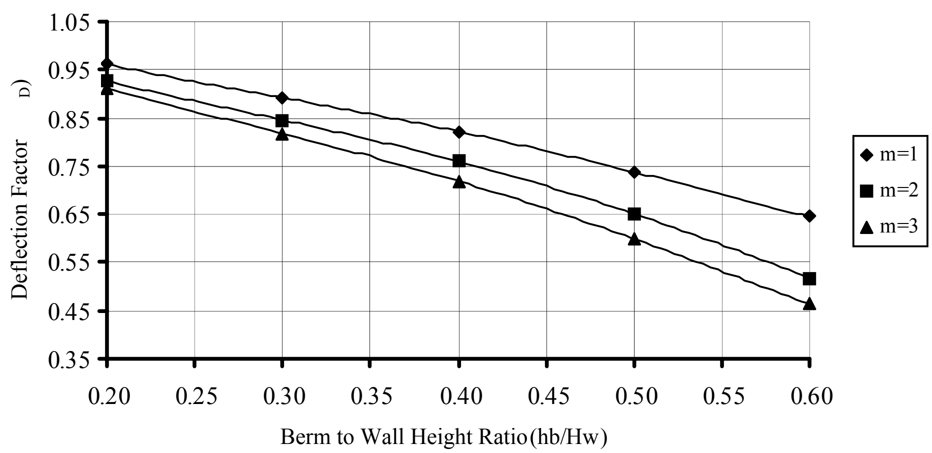

Figure (A5.9): Deflection Factor versus Berm to Wall Height Ratio
(φ =36° & Wall Group No. (1))

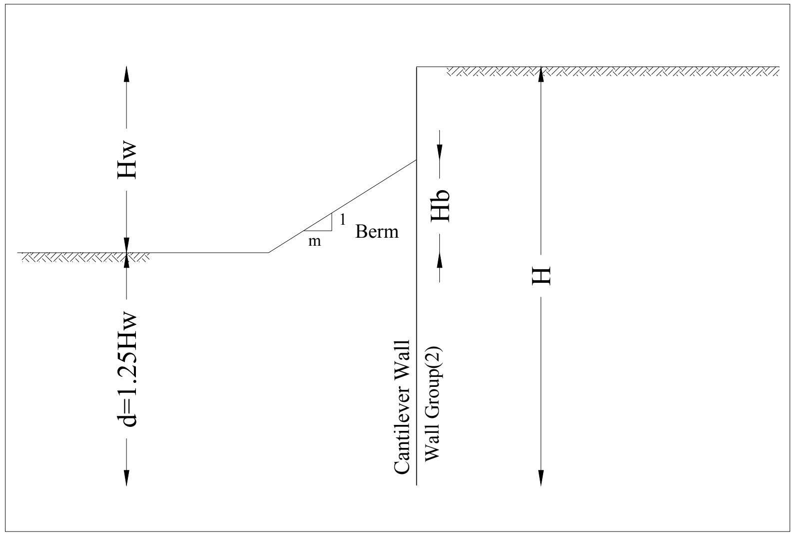

Figure (A5.10): Geometry of the Bermed Wall with Zero Top Width

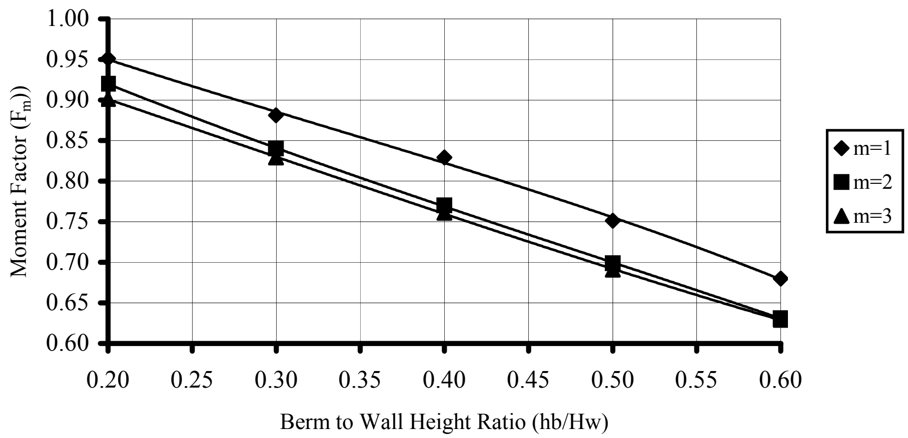

Figure (A5.11): Moment Factor versus Berm to Wall Height Ratio
(φ =36° & Wall Group No. (2))

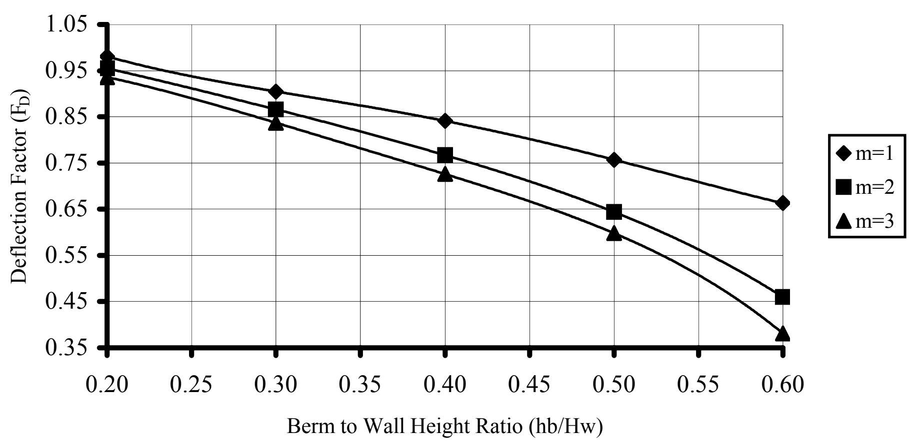

Figure (A5.12): Deflection Factor versus Berm to Wall Height Ratio
(φ =36° & Wall Group No. (2))

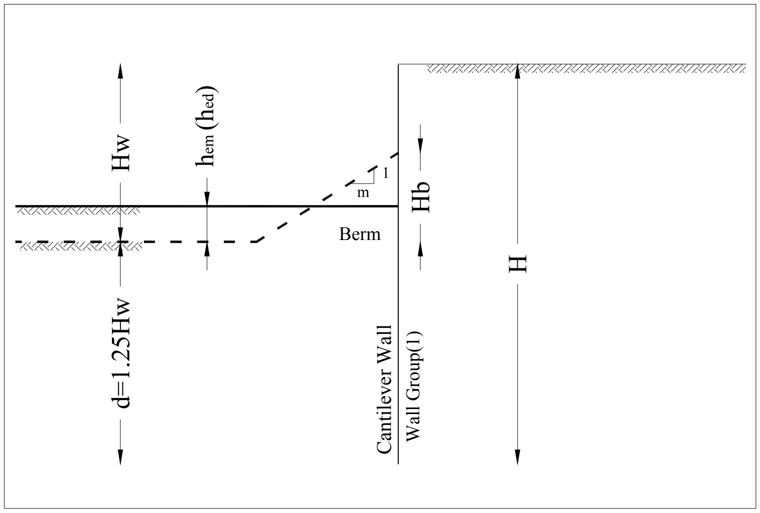

Figure (A5.13): Geometry of the Bermed Wall with Zero Top Width

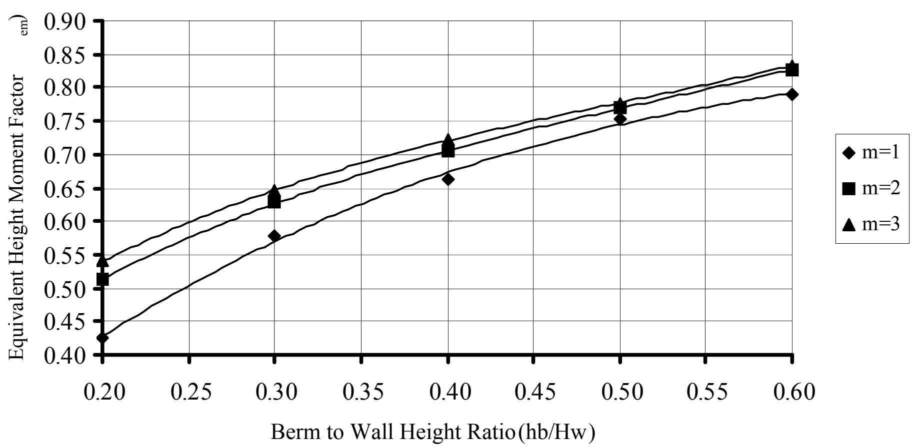

Figure (A5.14): Equivalent Height Moment Factor versus Wall to Berm Height Ratio
(φ =36°&Wall Group (1))

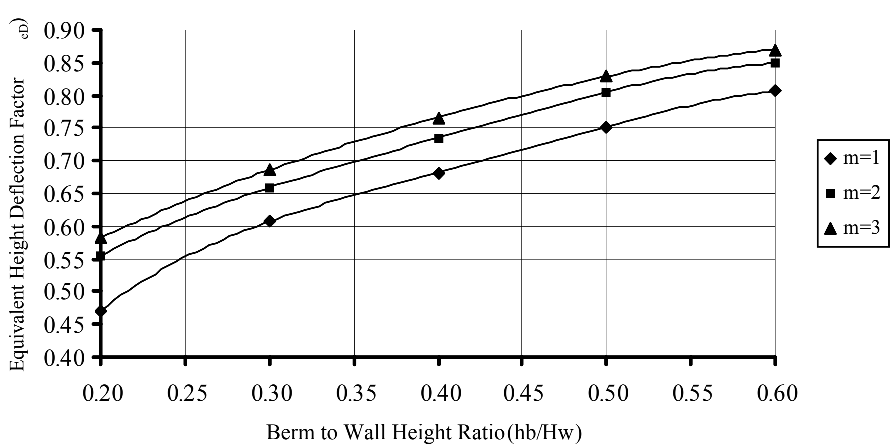

Figure (A5.15): Equivalent Height Deflection Factor versus Wall to Berm Height Ratio
(φ =36°&Wall Group (1))

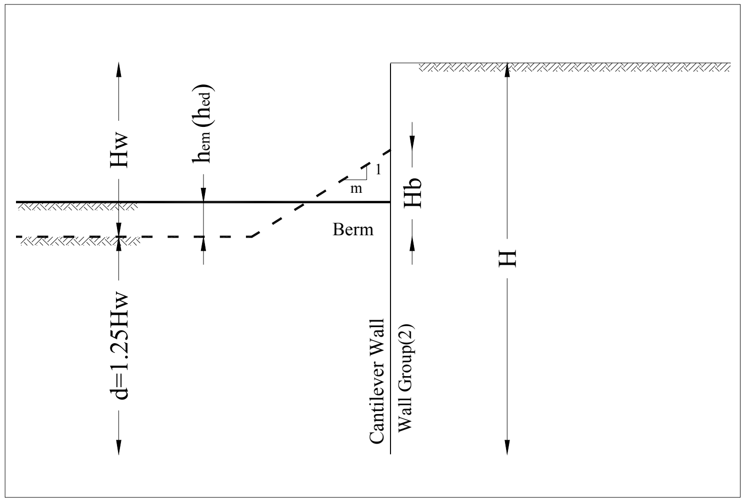

Figure (A5.16): Geometry of the Bermed Wall with Zero Top Width

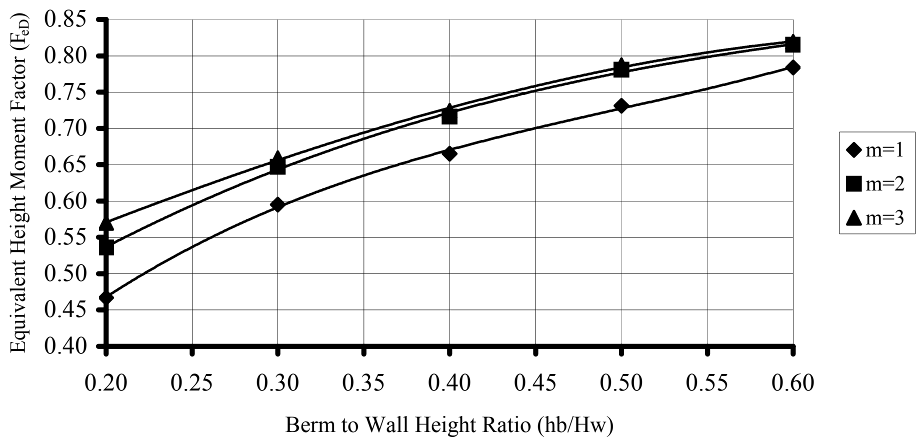

Figure (A5.17): Equivalent Height Moment Factor versus Wall to Berm Height Ratio (φ =36°&Wall Group (2))

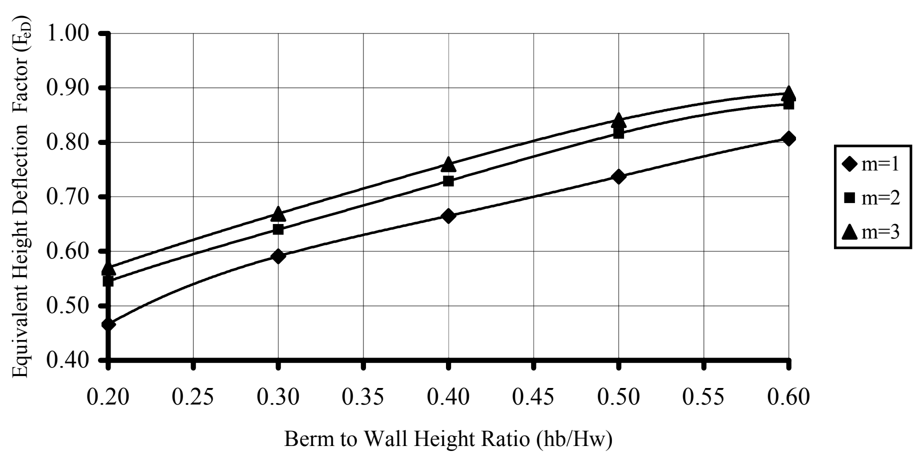

Figure (A5.18): Equivalent Height Deflection Factor versus Wall to Berm Height Ratio (φ =36°&Wall Group (2))

APPENDIX (6)

Laboratory Work Photos