ANALYSIS OF A RETAINING WALL CONSTRUCTED OF STRAP REINFORCED EARTH

by

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I. INTRODUCTION

1. Statement of the Problem

Retaining walls have in the past been classified into several principal types, i.e. gravity, cantilever, and flexible walls [Tschebotarioff(1)] [Bowles(2)], based on the method of achieving stability. There is a new type; the reinforced earth retaining wall, which was developed on the principle of steel reinforced earth. At this time, there are neither construction specifications nor criteria for design to be used by the engineers. This report suggests an elementary way to analyse and design a retaining wall constructed of reinforced earth.

2. Purpose of the Report

The purpose of this report is to suggest a way to analyse a strap reinforced earth retaining wall based on the theory of Coulomb as modified by Rankine concerning earth pressure. The Principle of reinforced earth is used to set up a series of tables which indicate to the designer the proportion of reinforcement in the earth mass, the relationship between the proportion of reinforcement and the separation of layers, and the width of the wall. In these tables some variables are held constant while others are allowed to vary. These tables allow the designer to arrive quickly at values for the proportion of reinforcement for each combination of variables.

3. Scope of the Report

A review of the theories of earth pressures and an introduction to the principle of the reinforced earth are given in this report. The major part of this report is aimed at developing a procedure for this type of retaining wall design. Secondly, a computer program was developed to be used to prepare a series of useful tables for the values of the proportion of reinforcement to earth. Finally, numerical examples and a conclusion from the writer summarize the results and suggest areas for future study.

II. REVIEW OF LITERATURE

A. Earth Pressures

1. Assumption Based on Coulomb's and Rankine's Theories

Coulomb(3) in 1776 was the first to develop an applicable theory of soil pressures and shearing resistance from a purely theoretical study of retaining structures. The basic assumptions for Coulomb's earth pressure theory were as followings:

(1). The soil is isotropic and homogeneous and possesses both internal friction and cohesion.

(2). The rupture surface is a plane surface.

(3). The friction forces are distributed uniformly along the plane rupture surface.

(4). The failure wedge is a rigid body.

(5). There is wall friction between the wall and the soil.

(6). Failure is a two dimensional phenomena, and the problem considered is a unit length of an infinitely long structure.

His assumptions limit the analysis to the ideal soil with many simplifing assumptions for ease of computation.

Rankine(4) in 1857 considered the soil to be in a state of plastic equilibrium and used essentially the same assumptions as Coulomb, except that he assumed no cohesion or wall friction which greatly simplified the calculation of problem. He studied the state of stresses with a loose granular mass with zero cohesion. His analysis was also based on the assumption that a slight deformation of the soil is sufficient to bring into

play its full frictional resistance and thus to produce immediately an active state if the soil tends to expand parallel to its surface and a passive state if it tends to compress parallel to its surface.

2. Vertical Earth Pressure

Fig. (1) shows the vertical stress at any depth, caused by the self-weight of soil, which can be computed simply by considering the weight of soil above that depth.

$$\sigma_v = \gamma Z$$

where σ_v is the vertical stress

γ is the unit weight of soil

Z is the depth

Lambe (5) stated "The unit weight is seldom constant with depth." "Usually a cohesionless soil becomes denser with depth becasue of the compression caused by the increasing vertical stress." If the unit weight of the soil varies continuously with depth, he suggests that the vertical stress can be evaluated by means of the integral

$$\sigma_v = \int_0^Z \gamma' \, dz, \qquad \text{where } \gamma' \text{ is variable}$$

In practice, the average unit weight of the soil through the depth is always used by engineers for design purposes.

3. Active and Passive Lateral Earth Pressures

A retaining wall constructed and backfilled with a cohe-

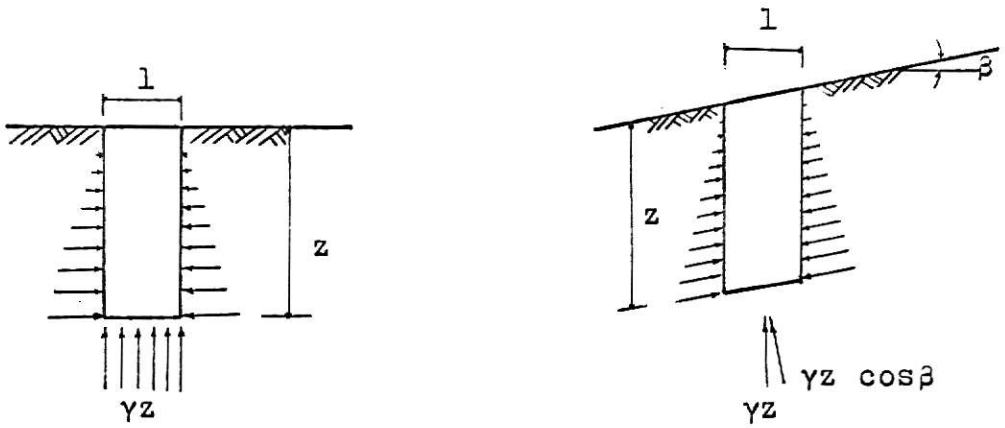


Fig. (1) (a) The vertical stress at depth z caused by the self-weight of soil with horizontal surface

(b) The vertical stress at depth z caused by the self-weight of soil with inclined surface

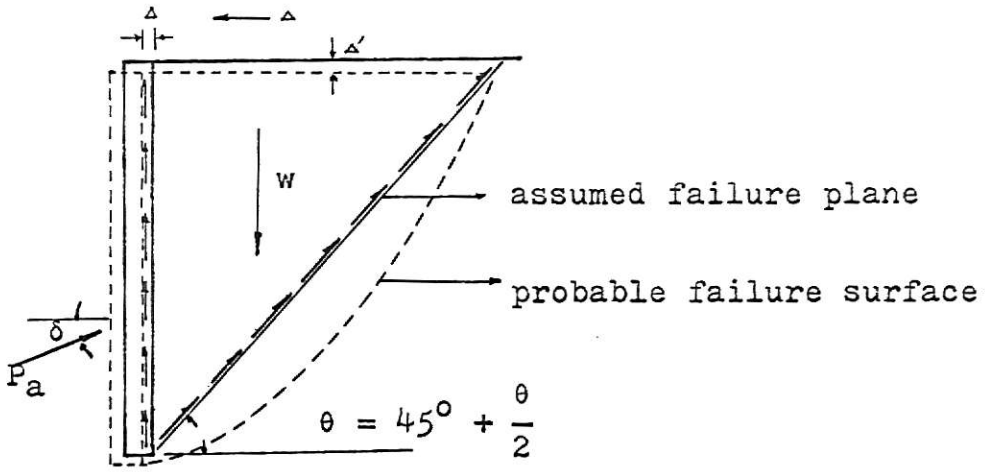


Fig. (2-a) Wall movement to develop active pressure

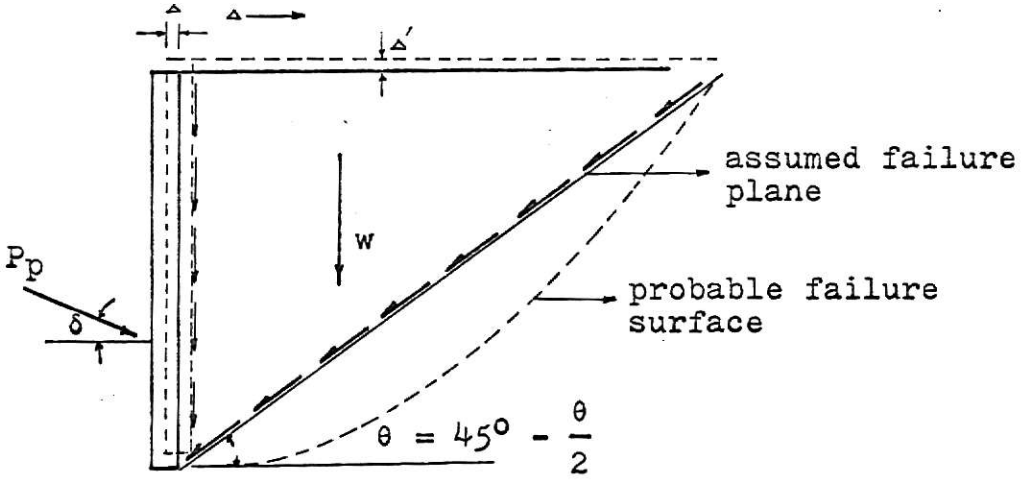


Fig. (2-b) Wall movement to develop passive pressure

sionless material as shown in Fig. (2-a), that is moved forward slightly results in the soil also moving forward. As the soil moves the friction forces become fully mobilized (Rankine's assumption), and an analysis of trial wedge as reported by Terzaghi(6) and Lambe(5) indicates that the critical surface is approximately a plane surface at an angle of

$$\theta = 45^{\circ} + \frac{\phi}{2}$$

with the horizontal plane, where ϕ is the internal friction angle of soil. At this point the failure wedge and driving weight are a minimum. This minimum is termed the active earth pressure.

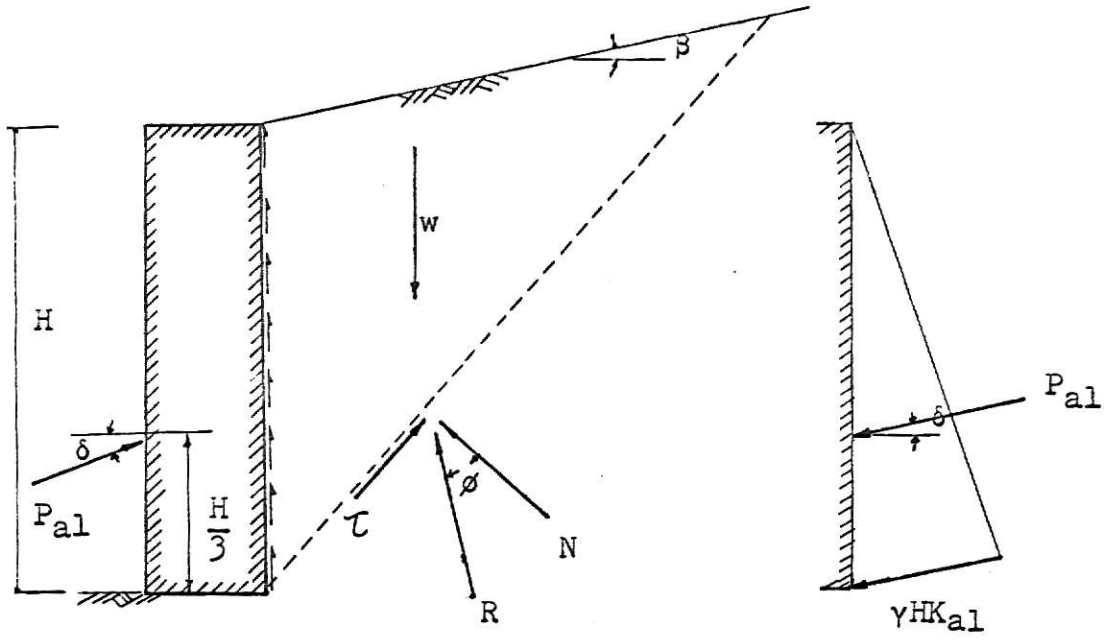
If the wall is moved into the backfill, Fig. (2-b), the failure wedge can be approximately by a plane surface at an angle of

$$\theta = 45^{\circ} - \frac{\phi}{2}$$

with the horizontal plane. For such a movement into the backfill, Bowles(2) says that the retaining wall must provide a sufficient push against the soil to overcome the frictional resistance along the rupture plane. The pressure developed in this case is termed the passive earth pressure.

4. Coefficients of Lateral Earth Pressures

To simplify computations these earth pressures are given in the forms of coefficients K_a and K_p. According to Bowles(2)



(a) (b)

Fig. (3) (a) Failure wedge and acting forces for active earth pressure with the wall friction considered

(b) Pressure diagram for active earth pressure

and Jumikis(7), Fig. (3) and Fig. (4) illustrate the concept of the coefficients of active and passive lateral earth pressures. From Fig. (3) the total active earth pressure

$$P_{al} = \frac{1}{2}\gamma H^2 \frac{\cos^2\phi}{\cos\delta\left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\beta)}{\cos\delta\cos\beta}}\right]^2} \tag{1}$$

$$K_{al} = \frac{\cos^2\phi}{\cos\delta\left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\beta)}{\cos\delta\cos\beta}}\right]^2} \tag{1'}$$

where K_{al} is the coefficient of active earth pressure in which the wall friction is considered. The pressure distribution is shown in Fig. (3-b).

The total passive earth pressure

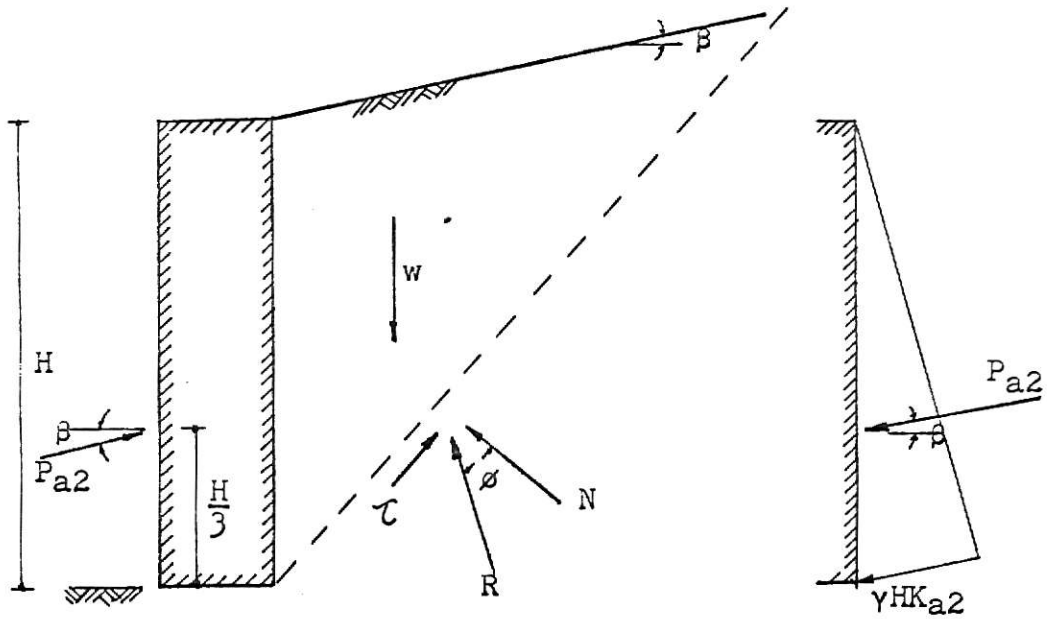
$$P_{pl} = \frac{1}{2}\gamma H^2 \frac{\cos^2\phi}{\cos\delta\left[1-\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\beta)}{\cos\delta\cos\beta}}\right]^2} \tag{2}$$

$$K_{pl} = \frac{\cos^2\phi}{\cos\delta\left[1-\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\beta)}{\cos\delta\cos\beta}}\right]^2} \tag{2'}$$

where P_{pl} acts downward to the normal of the back of the wall at the angle of wall friction δ, K_{pl} is the coefficient of passive earth pressure with the wall friction considered.

Fig. (4) shows the case of Rankine's earth pressure in which the wall friction is neglected.

The total active earth pressure



(a) (b)

Fig. (4) (a) Failure wedge and acting forces for active earth pressure with the wall friction neglected

(b) Pressure diagram for active Rankine earth pressure

$$P_{a2} = \frac{1}{2} \gamma H^2 \cos\beta \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}} \quad (3)$$

$$K_{a2} = \cos\beta \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}} \quad (3')$$

where K_{a2} is the coefficient of active earth pressure with the wall friction neglected.

The total passive earth pressure

$$P_{p2} = \frac{1}{2} \gamma H^2 \cos\beta \frac{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}} \quad (4)$$

$$K_{p2} = \cos\beta \frac{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}} \quad (4')$$

where K_{p2} is the coefficient of the passive earth pressure with the wall friction neglected.

Singh (8) points out that P_{a2} and P_{p2} must be parallel to the surface of the backfill as a consequence of Rankine's assumption of non-existence of frictional forces between the soil and the wall. Terzaghi (6) and Singh (8) also agree that frictional forces between the soil and the wall do develop with the movement of the wall and the resultant pressure is inclined to the normal to the wall at an angle that approaches the friction angle between the soil and the wall. This is the basic difference between Rankine's and Coulomb's theories.

In the case of

$$\delta = \beta = 0$$

Eqs. (1),(1'),(2),(2'),(3),(3'),(4),(4') would become

$$P_{a1} = P_{a2} = \frac{1}{2} \gamma H^2 \tan^2(45^\circ - \frac{\phi}{2})$$

$$K_{a1} = K_{a2} = \tan^2 (45^\circ - \frac{\phi}{2})$$

$$P_{p1} = P_{p2} = \frac{1}{2} \gamma H^2 \tan^2(45^\circ + \frac{\phi}{2})$$

$$K_{p1} = K_{p2} = \tan^2(45^\circ + \frac{\phi}{2})$$

B. Principle of Reinforced Earth

The principle of reinforced earth was first generally introduced by Vidal (9) in 1969. There are some major concepts in reinforced earth, which must be mastered to develop the design of straps reinforced earth retaining walls.

1. Reinforced Earth

Reinforced earth is a material formed by combining earth and steel reinforcement. "Earth" covers all types of soil found in nature, including both granular soil and soils which exhibit cohesion. In this report the earth was assumed to be made up of strictly non-cohesive soil. When rectilinear reinforcement is introduced horizontally in this earth the whole mass exhibits some cohesion, which arises from friction of grains of earth against the reinforcement forming a body of reinforced earth.

It is assumed that there is grain-reinforcement friction

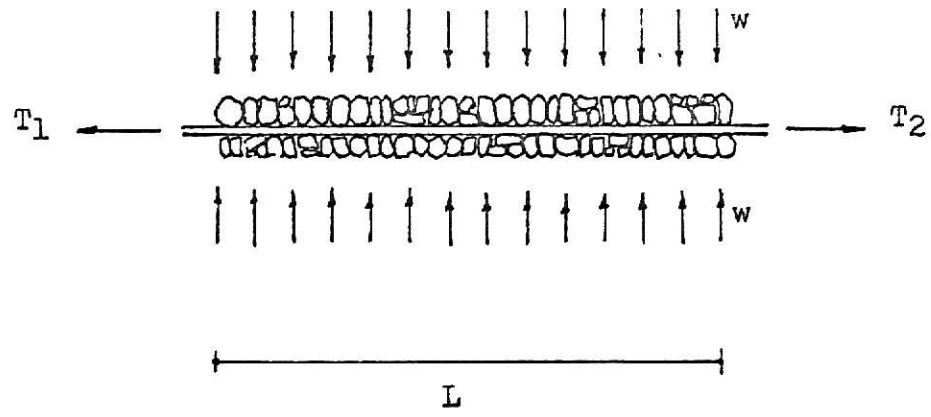


Fig. (5-a) A reinforcement is connected to the soil grains by tensions T_1 and T_2 and with the stress w normal to the reinforcement over a length L

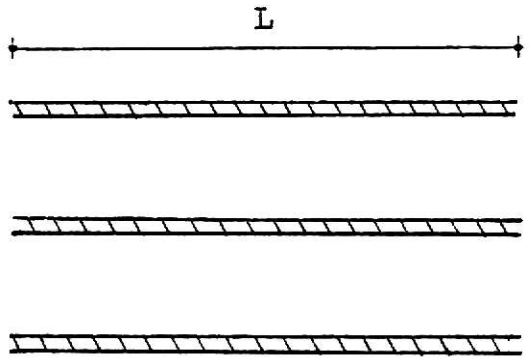


Fig. (5-b) Top view of the reinforcement distribution

without sliding, and that the reinforcement is connected to the earth and properly placed and designed.

2. Friction between Earth and Reinforcement

According to Vidal (9) friction is the basis of the theory of reinforced earth.

A reinforcement is connected to the soil grains by tensions T_1 and T_2 as shown is Fig. (5-a). If the stress in the earth perpendicular to the plane of the reinforcement has the value w (the force normal to the reinforcement over a length L) and there is no sliding between earth and reinforcement, and there is a relationship

$$\frac{\Delta T}{2wL} < f \qquad (5)$$

where $\Delta T = T_1 - T_2$

f is the coefficient of friction between earth and reinforcement.

Formula (5) assumes that the reinforcement members are flat and that a layer of reinforcement forms a plane. In reality the reinforcements are in flat bands of limited width spaced at finite distances from each other as shown in Fig. (5-b).

If K_r is the proportion of reinforcement per length,

formula (5) becomes

$$\Delta T < 2wL\ K_r\ f$$

$$\Delta T = 2wL\ K_r\ \frac{f}{S} \qquad (6)$$

where S is the safety factor

3. Stresses in Earth and Reinforcement

Vidal (9) points out that there are some difficulties in calculating forces in reinforced earth, which result from dealing with a composite non-isotropic material. But he states that this does not interfere with the validity of Mohr's circle which makes it possible to represent the stresses in the earth around a point.

If a cube of non-cohesive earth, Fig. (6-a), is subjected to a compression stress N_1 on its two faces, under the stress condition shown in Fig. (6-b), it can not remain in equilibrium because the Mohr's circle C_1 cuts the failure envelope [Singh (8)]. The cube can only be stable when compression force N_2 is at least equal to $K_a N_1$, acting on its other axial faces, as shown in Fig. (7-a).

where

$$K_a = \tan^2 (45^\circ - \frac{\phi}{2})$$

in which case the Mohr's circle C_2 becomes tangential to the failure envelope. According to Terzaghi (6) this means failure under the active-pressure condition is just occurring. If N_2

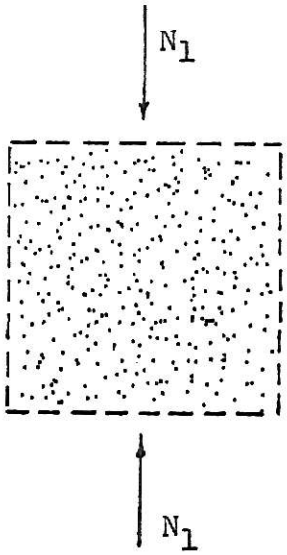


Fig. (6-a) A cube of non-cohesion earth is subjected to a compressive force N_1 on its two faces

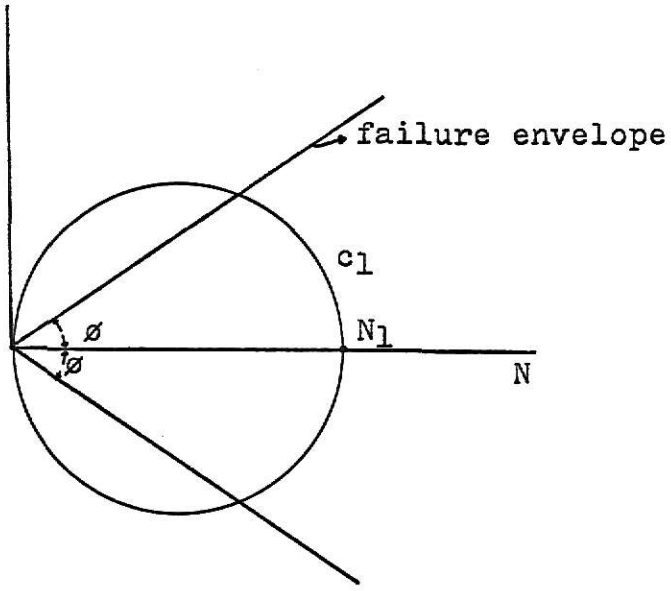


Fig. (6-b) Mohr's circle represents the state of the stress in the unbounded earth

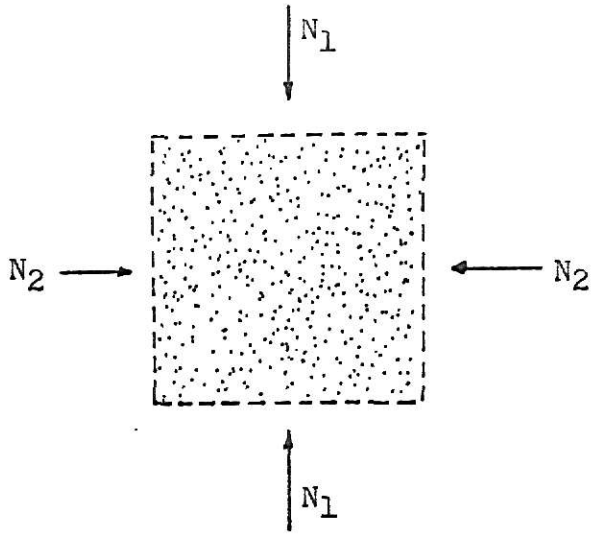


Fig. (7-a) A cube of non-cohesive earth is subjected to a compressive force N_1 on its two faces, and N_2 on its other axial two faces

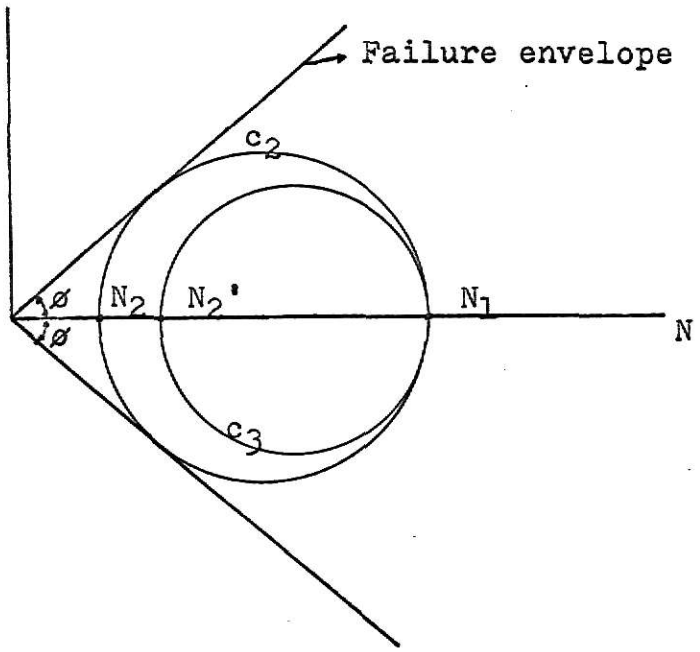


Fig. (7-b) Graphic representation of state of the stress at failure, c_2 c_3 represents the earth in elatic equilibrium

is greater than $K_a N_1$ the Mohr's circule C_3, Fig. (7-b), shows the earth in elastic equilibrium.

In the absence of reinforcement these stresses, N_2 and N_2' can only be produced by external forces.

Vidal (9) considered an elementary cube of reinforced earth, Fig. (8-a), which is assumed to be oriented so that the reinforcement is arranged perpendicular to the direction of the compression force N_1. It is also assumed that there is no sliding between the reinforcement and the earth particles. Thus the neighboring particles A and B are rigidly connected by the reinforcement, and everything acts as if the two plates A' and B' as shown in Fig. (8-b), formed of the external particles which can produce stresses on these two cube faces, are connected by the reinforcement.

Vidal (9) concludes that when the cube is subjected to a compressive stress N_1 it does tend to expand along the reinforcement members, and that sliding of the particles within the cube is impossible up to the point where the compression forces N_2 become equal to $K_a N_1$. At this point the corresponding Mohr's circle obviously becomes tangential to the failure envelope.

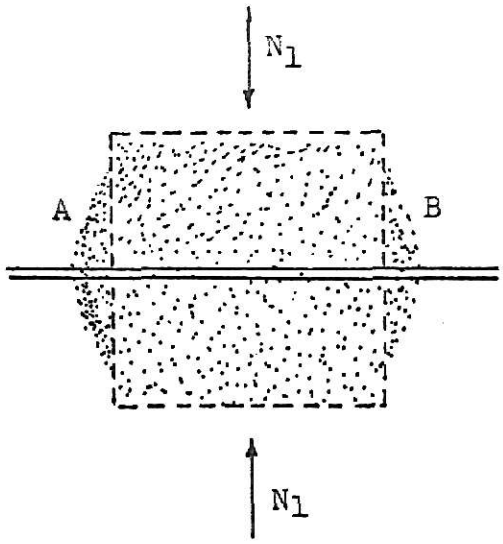


Fig. (8-a) A reinforcement is introduced horizontally into the cube of non-cohesive earth which is subjected to a vertical compressive force N_1

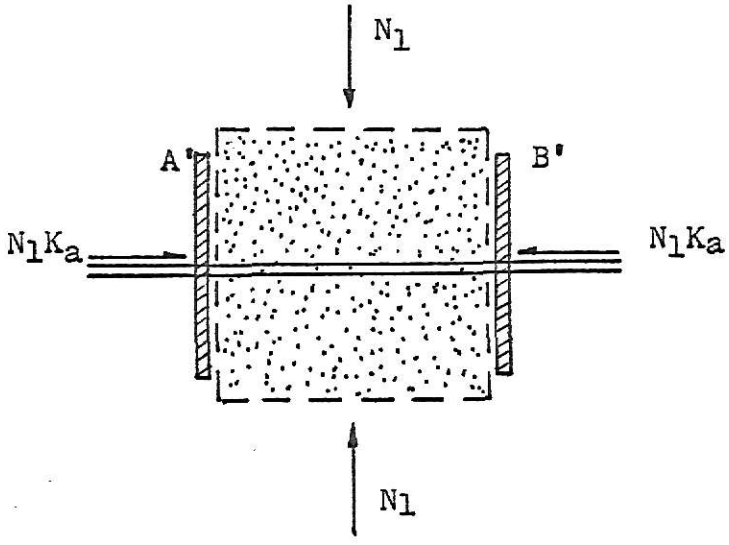


Fig. (8-b) A cube of reinforced earth is in equilibrium

III. RETAINING WALL DESIGN DEVELOPED BY THE PRINCIPLE OF REINFORCED EARTH

Retaining walls are always designed to retain the thrust from the earth mass behind the wall by its full or partial self-weight. Fig. (9-a) shows a wall in Rankine's case (a smooth vertical face and with a cohesionless material in the backfill are assumed) with a driving force P_a against which it must provide adequate stability against sliding and overturning. Fig. (9-b) shows how the horizontal pressure distribution along the wall face with increasing depth.

According to the principle of reinforced earth the frictional forces between the soil and the reinforcement are used to balance the horizontal force, $P_a \cos\beta$.

Fig. (10) indicates the reinforcement introduced into the soil mass. As long as the reinforced earth is stable; no sliding will occur in the earth, the reinforced earth as a whole acts as a gravity wall with a vertical face. The other necessary design computation is checking it against sliding on the base or overturning at the toe, due to the driving force of the earth behind the reinforced earth wall.

The analysis and design of the reinforcing strap for a reinforced earth retaining wall involve the following steps:

Step (1). Calculate the horizontal driving force P_H in the reinforced earth.

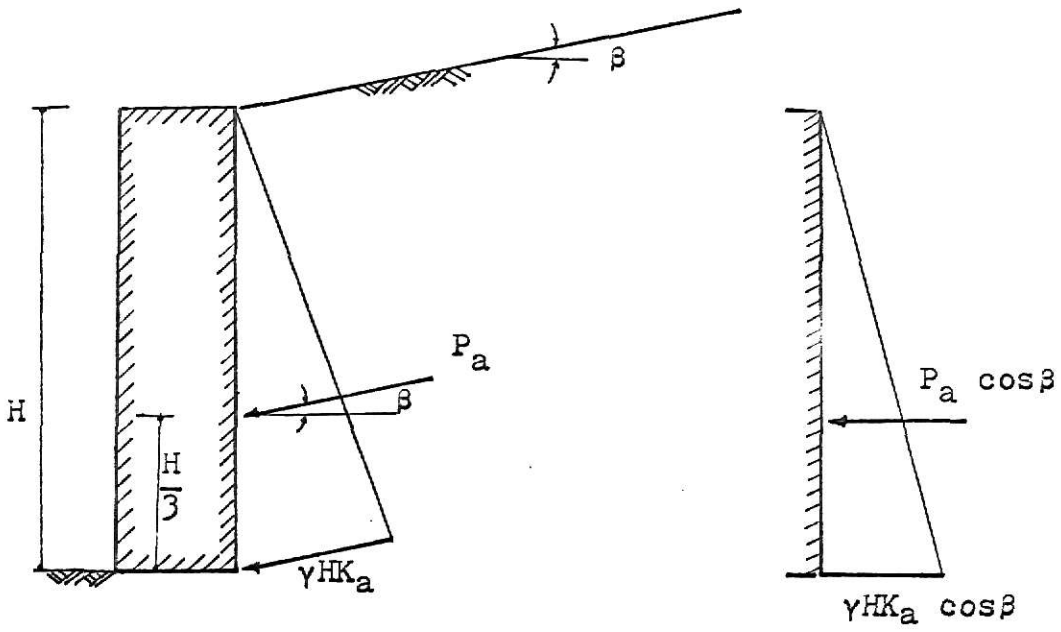


Fig. (9) (a) Active earth pressure diagram in Rankine's case

(b) Horizontal active pressure distribution along the wall with increasing depth.

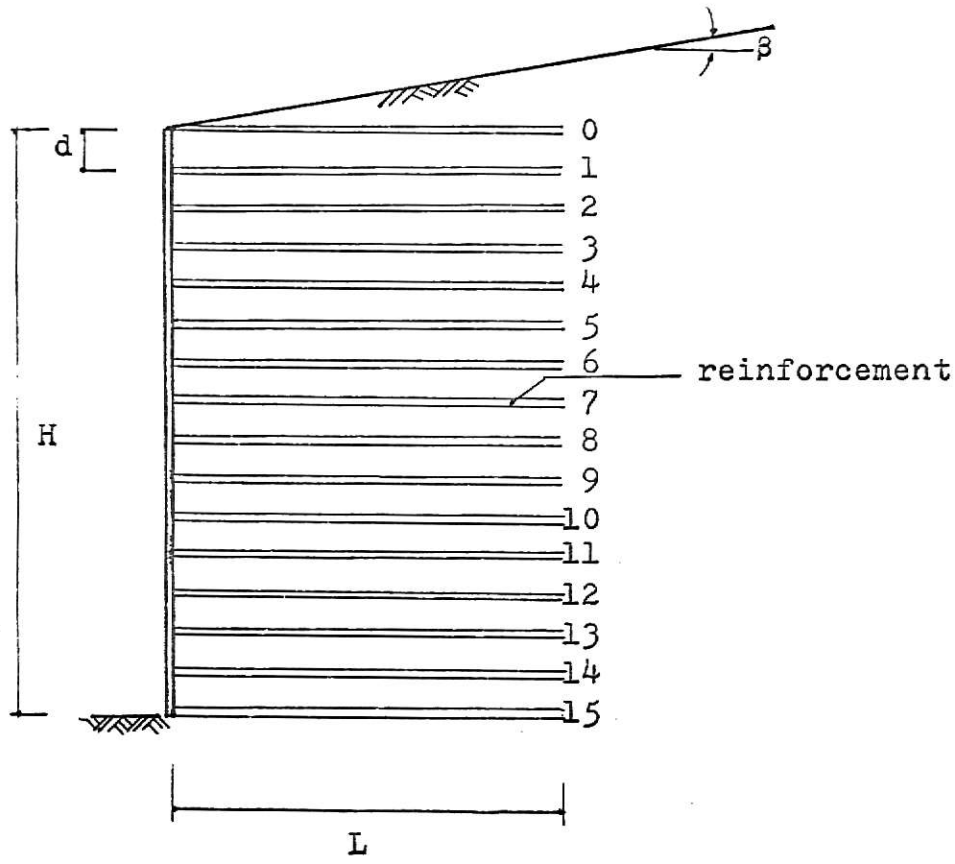
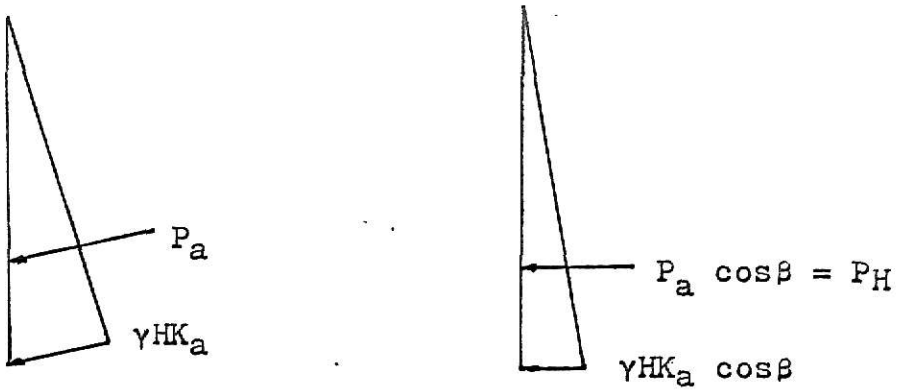


Fig. (10) A retaining wall constructed of strap reinforced earth



According to Eq. (3) and Eq. (3')

$$P_a = \frac{1}{2}\gamma H^2 \cos\beta \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}}$$

$$K_a = \cos\beta \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}}$$

The horizontal driving force would be

$$P_H = P_a \cos\beta = \frac{1}{2}\gamma H^2 K_a \cos\beta \qquad (7)$$

Step (2). Calculate the total possible resistance between the earth and the reinforcement.

From Fig. (10)

H ---------- height of the wall

L ----------width of the wall

γ ---------- unit weight of the soil

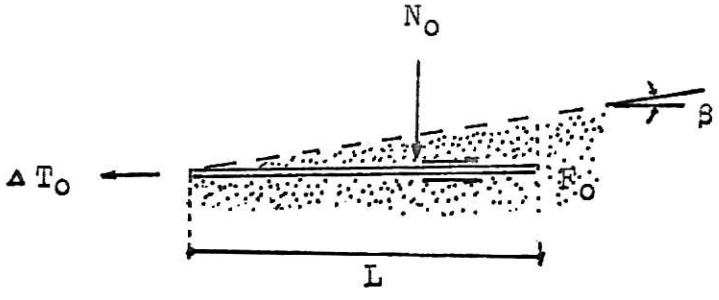
β ---------- angle of the backfill

d ---------- distance between each layer of reinforcements

f ---------- coef. of friction between soil and reinforcement

K_r ---------- proportion of reinforcement per foot wall

At layer No. (0)



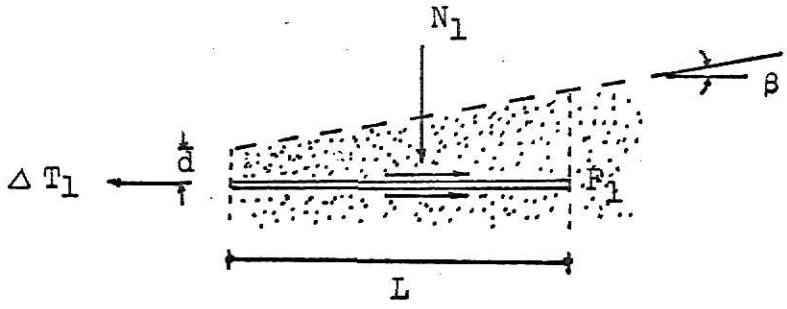
N_o is the soil weight above the layer

according to Eq. (6) the resistance force is

$$F_o = 2\ N_o\ K_r\ \frac{f}{S}$$

$$F_o = 2 \cdot \frac{\gamma}{2} L^2\ \tan\beta \cdot K_r \cdot \frac{f}{S}$$

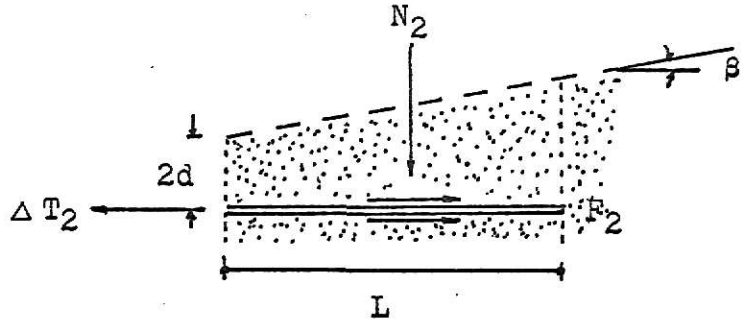
At layer No. (1)



the resistance force is

$$F_1 = L\ (2d + L\ \tan\beta) \cdot \gamma \cdot K_r \cdot \frac{f}{S}$$

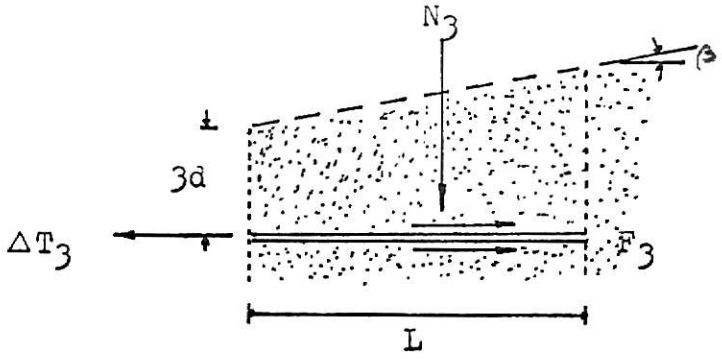
At layer No. (2)



the resistance will be

$$F_2 = L\ (4d + L\ \tan\beta)\ \gamma \cdot K_r \cdot \frac{f}{S}$$

At layer No. (3)



the resistance will be

$$F_3 = L\ (6d + L\ \tan\beta) \cdot \gamma \cdot K_r \cdot \frac{f}{S}$$

Similarly, the resistance force at layer No. (n) is

$$F_n = L\ (2nd + L\ \tan\beta) \cdot \gamma \cdot K_r \cdot \frac{f}{S}$$

Then it follows that the total resistance force

$$F = \sum_{i=0}^{n} F_i$$

$$F = [L^2(n+1)\ \tan\beta + 2Ld(1+2+\cdots\cdots n)]\gamma \cdot K_r \cdot \frac{f}{S}$$

$$F = \left(\frac{H}{d} + 1\right)\ (L^2 \tan\beta + LH)\gamma \cdot K_r \cdot \frac{f}{S} \qquad (8)$$

where $n = \frac{H}{d}$, number of layers

Step (3). Determine K_r values.

The reinforcing members are stable against sliding if

$$P_H = \sum_{i=0}^{n} \Delta T_i \leq F = \left(\frac{H}{d} + 1\right)\left(L^2 \tan\beta + LH\right) \gamma K_r \frac{f}{S}$$

From Eq. (7) and Eq. (8)

$$\frac{1}{2} \gamma H^2 K_a \cos\beta = \left(\frac{H}{d} + 1\right)\left(L^2 \tan\beta + LH\right) \gamma K_r \frac{f}{S}$$

where $f = \tan\alpha$, α is the friction angle between soil and reinforcement.

If $S = 2$, then

$$K_r = \frac{H^2 \cos\beta \cos\alpha K_a}{\left(\frac{H}{d} + 1\right)(L^2\tan\beta + LH)\sin\alpha} \tag{9}$$

K_r is obviously a function of H, L, β, α, d, and K_a. In turn L depends on the active thrust from the backfill of the reinforced earth wall, and on the sliding resistance of the base when the reinforced earth is considered as a whole.

Step (4). Check sliding of the wall.

From Fig. (11) the active horizontal force from the backfill is

$$P_H' = P_a' \cos\delta = P_a' \cos\phi \tag{10}$$

but the resistance force on the base is equal to

$$\begin{aligned} R_f &= (w_1+w_2)K_r L \tan\alpha + (w_1+w_2)\, L\, (1-K_r) \tan\phi \\ &= L(w_1+w_2)\left[\tan\phi + K_r(\tan\alpha - \tan\phi)\right] \end{aligned} \tag{11}$$

where w_1 is the weight of soil body ABCD

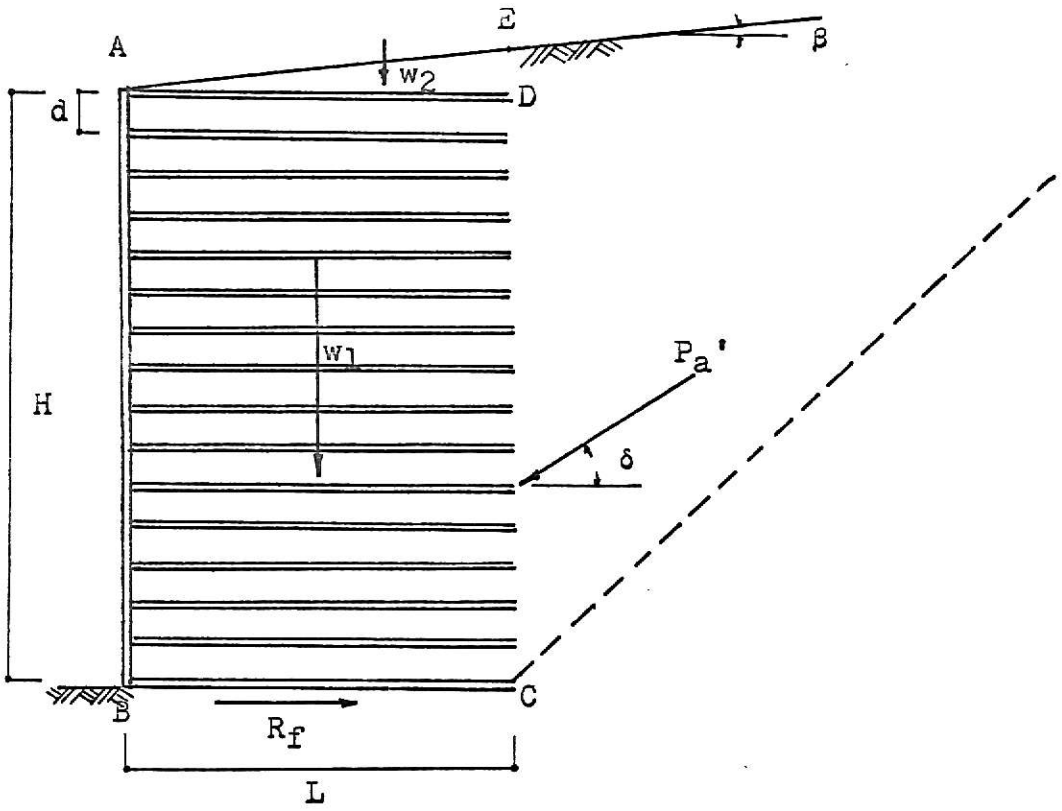


Fig. (11) Forces acting on a strap reinforced earth retaining wall

w_2 is the weight of soil body ADE

Then,

$$S.\ F. = \frac{R_f}{P_H'} \geq 1.5$$

must be satisfied.

Step (5). Check overturning about the toe

$$M_o = w_1 \frac{L}{2} + w_2 L \frac{2}{3} \tag{12}$$

$$M_t = P_H' \frac{(H+L\tan\beta)}{3} - P_v' \cdot L \tag{13}$$

where M_o is the moment about the toe, produced by the reinforced earth body

M_t is the moment about the toe, produced by the thrust from the backfill

$$P_v' = P_a' \sin\delta = P_a' \sin \phi$$

$$w_1 = H \cdot L \cdot \gamma$$

$$w_2 = \frac{1}{2} L^2 \tan\beta \cdot \gamma$$

Then,

$$S.\ F. = \frac{M_o}{M_t} \geq 2$$

must be satisfied.

Step (6). Select the cross section of reinforcement.

The highest horizontal driving stress is at the bottom of the wall. It is assumed that the layer of reinforcement at the base takes the stress such that

$$F_n = L\,(2nd + L\tan\beta)\cdot \gamma \cdot K_r \cdot \frac{f}{S}$$

Then,

$$A = \frac{F_n}{f_r}$$

where f_r is the working allowable strength of the reinforcement

A is the needed cross section of each strip reinforcing member per foot wall

In discussion of the cross section of the reinforcement there are many kinds of shapes such as strips, wire mesh, steel cable, to be possible used as long as they give the necessary friction surfaces in the longitudinal direction.

If round reinforcement is selected instead of flat rectilinear reinforcement, Eq. (6) would become

$$\Delta T = 2\pi r \cdot L \cdot w \cdot \gamma \cdot K_r' \cdot \frac{f}{S}$$

where r is the radius of the rod

K_r' is the number of rods per foot wall

w is the average pressure around the rod

In this report only the flat strip reinforcement is considered.

IV. NUMERICAL EXAMPLES

"Design a retaining wall constructed of reinforced earth, which is to retain an embankment 30 feet high. The backfill slopes 10° to the horizontal, $\phi = 35^{\circ}$, and $\gamma = 120$ pcf. The bearing capacity of the base is assumed to be high enough to stand the weight of the wall."

As far as this example is concerned, a lot of choices can be considered from appendix A_2. First of all we should determine how wide to design the wall. Secondly we also should decide the separation between the layers of reinforcement.

Here we select arbitrarily for the values of L and d

$$L = 14' \ , \quad d = 1'$$

then from Table (29)

$$H = 30' \ , \quad \phi = 35^{\circ} \ , \ \beta = 10^{\circ} \ , \quad L = 14' \ , \quad d = 1'$$

and we obtain

$$K_r = 0.456$$

where the units for K_r are inches per foot of wall. This means that a strip of reinforcement 0.456 inches wide and 14 feet long would be used in each layer per foot of wall.

If we make an other choice of

$$L = 15' \ , \quad d = 2'$$

with the same data as before

then

$$K_r = 0.8836$$

There are some other things left for the designer to consi-

der such as the allowable tensile strength of the reinforcement, such that a reasonable cross section for the strap reinforcement may be selected to prevent overstressing the steel strap.

Finally, there is a special case when

$$n = \frac{H}{d}$$

is not an integer. Then an additional layer of reinforcement which is lain on the top of the base is necessary to make up the height of the wall. This is illustrated as following:
In the case of

$$H = 20' \ , \quad \phi = 35^{\circ} \ , \quad \beta = 10^{\circ} \ , \quad L = 9' \ , \quad d = 3'$$

from Table (17) we get

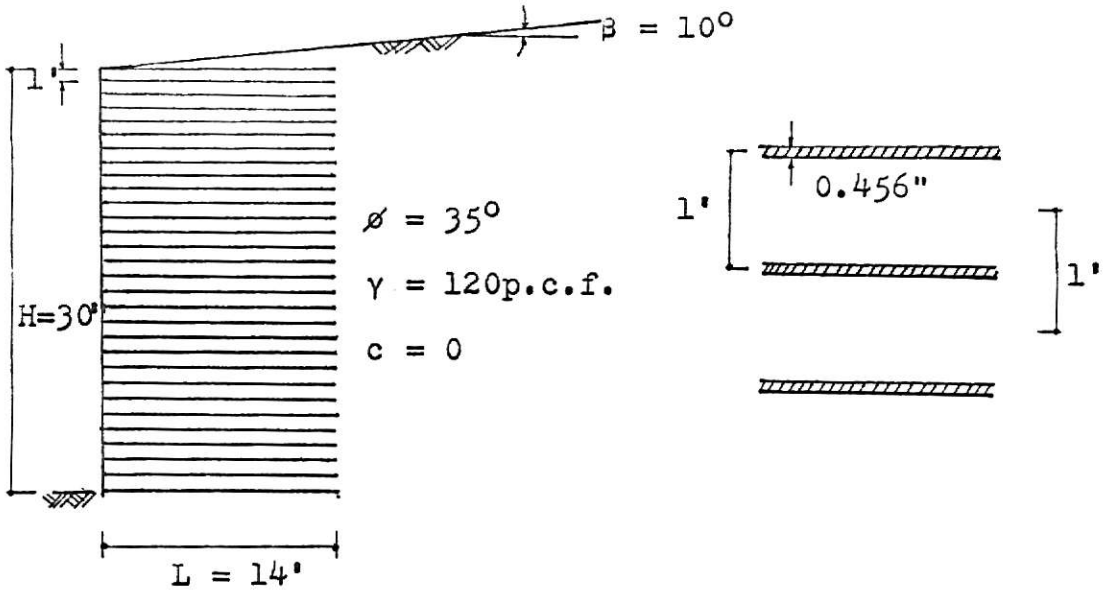
$$K_r = 1.917$$

but

$$n = \frac{20}{3} = 6.6$$

an additional layer (20-3x6 = 2') is used at the bottom as shown in Fig. (13).

The following figures show how the layers of reinforcement are distributed and show the relationships between the data.

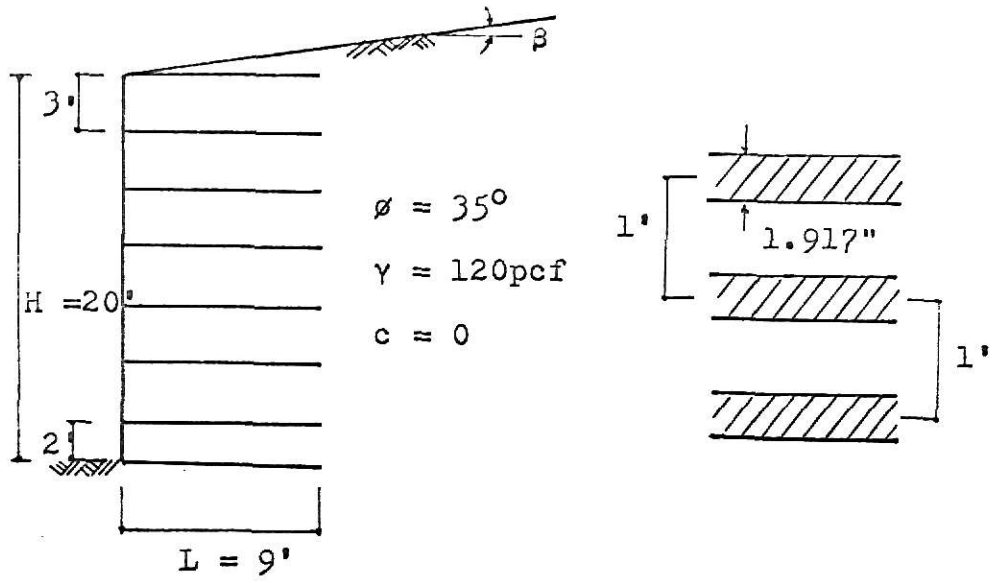


(a) (Not to Scale) (b)

Fig. (12) Numerical example

(a) A strap reinforced earth retaining wall
H = 30' ø = 30° L = 14' d = 1'

(b) Top view of reinforcement with the proportion of 0.456" per foot of wall



(a) (b)

Fig. (13) Numerical example

(a) A strap reinforced earth retaining wall
H = 20', ø = 35°, L = 9', d = 3'

(b) Top view of reinforcement with the proportion of 1.917" per foot of wall

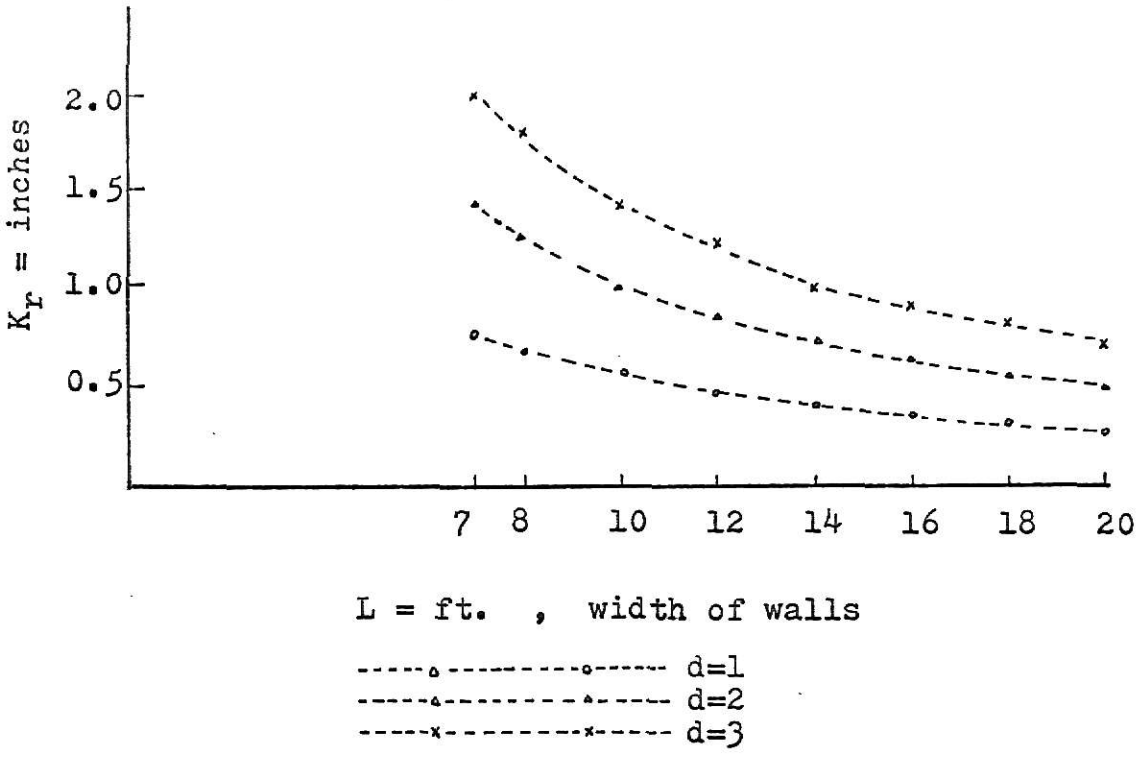
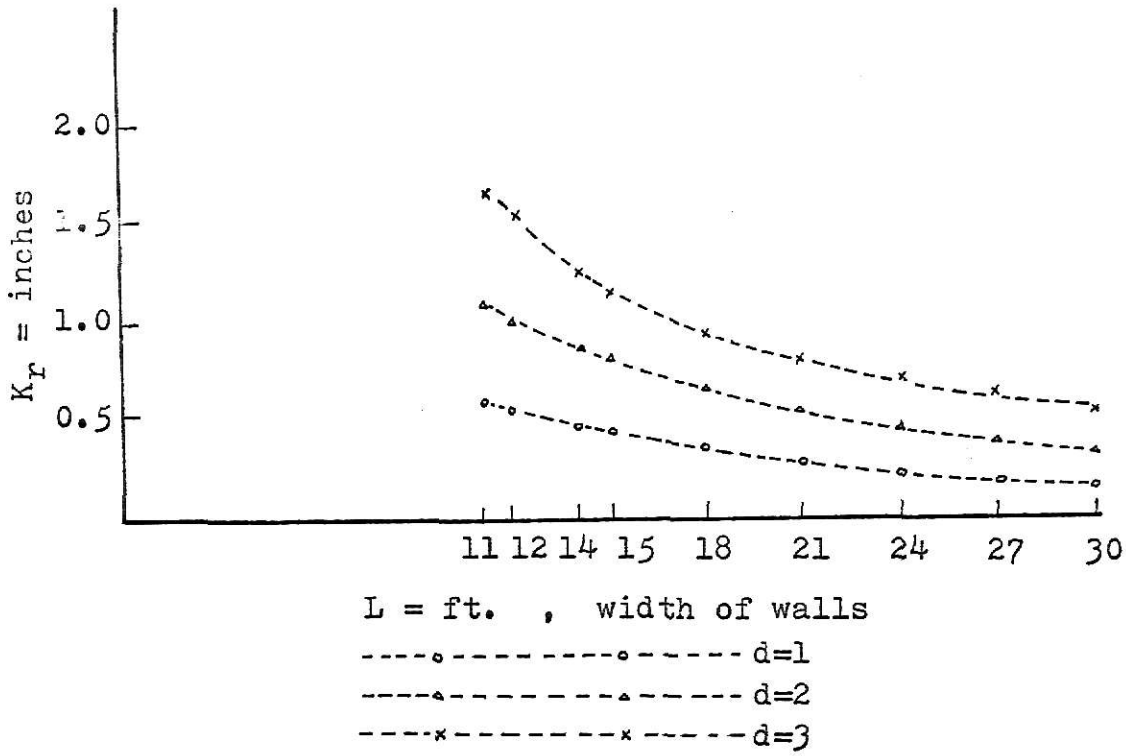
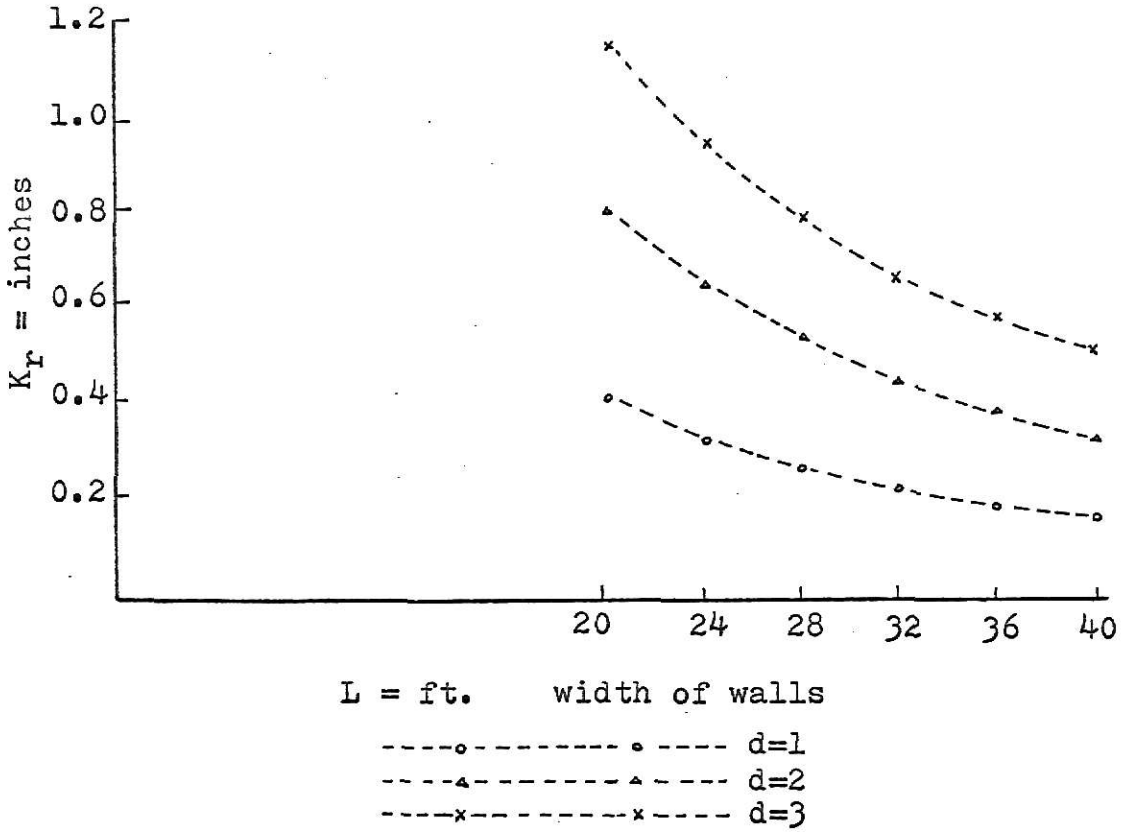


Fig. (14) K_r values with different separations of layers of the reinforcement, the wall height is 20 feet, and the internal friction angle of the soil ø = 40°, the Backfill β = 0°



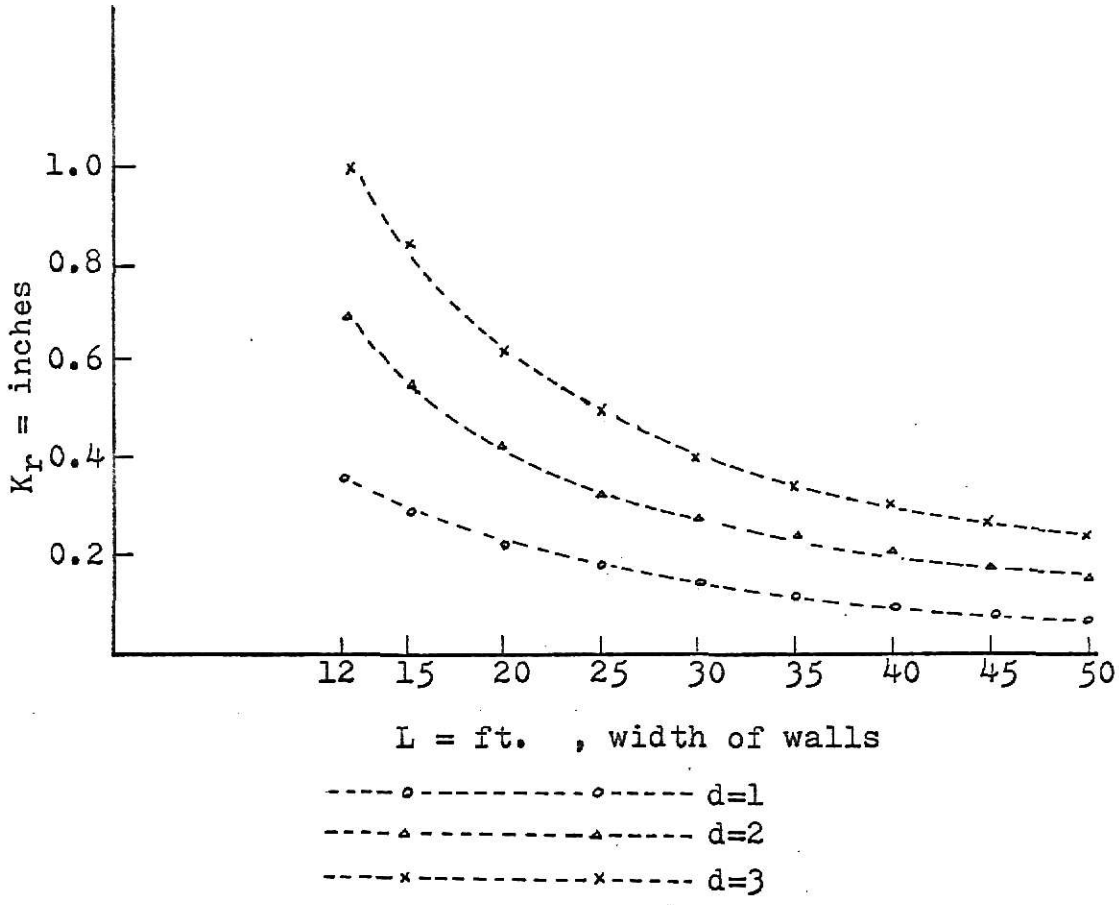
H = 30', $\phi = 35^{\circ}$, $\beta = 10^{\circ}$

Fig. (15) K_r values with different separations of layers of the reinforcement, the wall height is 30', and the internal friction angle of the soil $\phi = 35^{\circ}$, the backfill $\beta = 10^{\circ}$



H = 40', $\phi = 30^{\circ}$, $\beta = 20^{\circ}$

Fig. (16) K_r values with different separations of layers of the reinforcement, the wall height is 40feet, and the internal friction angle of the soil $\phi = 30^{\circ}$, the backfill $\beta = 20^{\circ}$



H = 50', $\phi = 45^{\circ}$, $\beta = 0^{\circ}$

Fig. (17) K_r values with different separations of layers of the reinforcement, the wall height is 50 feet, and the internal friction angle $\phi = 45^{\circ}$ the backfill $\beta = 0^{\circ}$

V. CONCLUSIONS

(1). Both the Rankine and Coulomb earth pressure theories are useful in the analysis of retaining walls.

(2). The friction between the earth and the reinforcement is the basis of the theory of reinforced earth. The fundamental calculation of the friction between earth and reinforcement is extremely simple. As long as the stresses in the earth and the reinforcement are known, only a simple procedure is needed to design such a retaining wall.

(3). When data such that H, ϕ, β, L, d, f are determined, a strap reinforced earth retaining wall can be designed simply by looking up the values of K_r and selecting the cross section of the reinforcing member, where

H --------- height of the wall

L --------- width of the wall

γ --------- unit of the soil

ϕ --------- internal friction angle of the soil

β --------- angle of the backfill

d --------- distance between each layer of reinforcement

f --------- coeff. of friction between soil and reinforcement

K_r -------- proportion of reinforcement per foot wall

$$K_r = \frac{H^2 \cos\beta \cos\alpha K_a}{\left(\frac{H}{d} + 1\right)\left(L^2 \tan\beta + LH\right)\sin\alpha}$$

where

$f = \tan\alpha$, α is the friction angle between soil and reinforcement.

(4). When the height of the wall is held constant, the wider the wall the smaller the proportion of reinforcement is needed. The proportion of reinforcement increases as the separation of each layer of reinforcement increases with the height and the width of the wall held constant.

(5). The analysis for a retaining wall constructed of reinforced earth is similar to that for a gravity wall.

VI. SUGGESTIONS FOR FURTHER RESEARCH

(1). Since scale model tests are often an effective method of checking theoretical calculations, it is suggested that scale models be constructed in order to prove the accuracy of the theory of reinforced earth.

(2). A study of the influence of the stresses in the reinforced earth due to earthquakes and of the stability of the structure under the influence of the external forces induced by earthquakes is proposed.

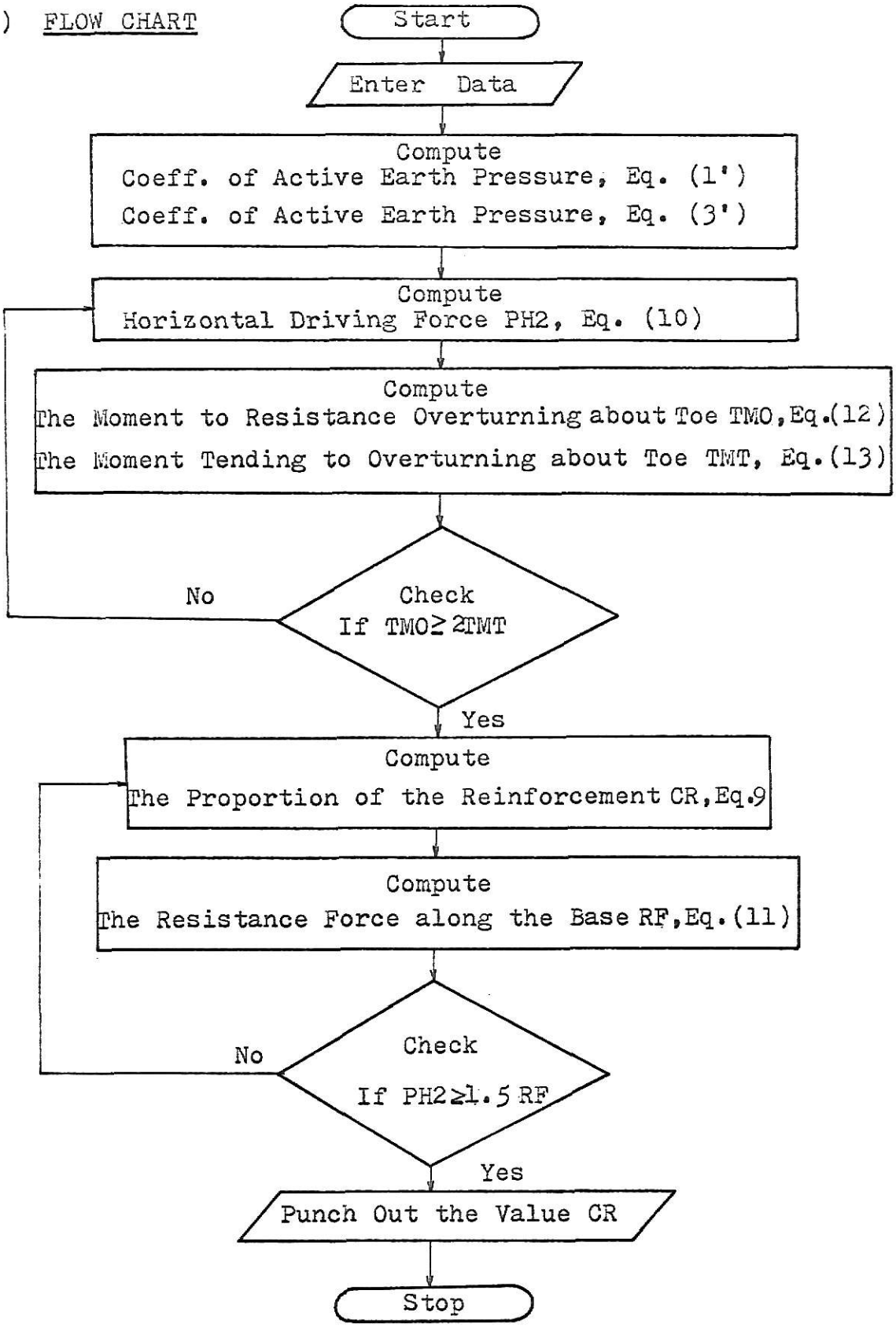
(3). As far as the material is concerned, a retaining wall constructed of reinforced earth could appear to be more economical than a reinforced concrete wall. However, a study of the relative economy of such structures from the view points of the time factor and their simplicity of construction is also suggested.

APPENDIX A

(a) Flow Chart of the Computer Program

(b) The Computer Program

(a) FLOW CHART


Start
Enter Data
Compute
Coeff. of Active Earth Pressure, Eq. (1')
Coeff. of Active Earth Pressure, Eq. (3')
Compute
Horizontal Driving Force PH2, Eq. (10)
Compute
The Moment to Resistance Overturning about Toe TMO, Eq.(12)
The Moment Tending to Overturning about Toe TMT, Eq.(13)
Check
If TMO≥2TMT
No
Yes
Compute
The Proportion of the Reinforcement CR, Eq.9
Compute
The Resistance Force along the Base RF, Eq.(11)
Check
If PH2≥1.5 RF
No
Yes
Punch Out the Value CR
Stop

ILLEGIBLE DOCUMENT

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(b)

```
C     THIS PROGRAM COMPUTES THE PROPORTION OF THE
C     REINFORCEMENT USED IN THE ANALYSIS OF [illegible]
C     CONSTRUCTION OF STRAP REINFORCED EARTH
C     H IS THE HEIGHT OF THE WALL
C     BETA IS THE ANGLE OF THE BACKFILL
C     D IS THE DISTANCE BETWEEN EACH LAYER OF REINFORCEMENTS
C     PHI IS THE FRICTION ANGLE OF SOIL
C     WL IS THE WIDTH OF THE REINFORCED EARTH WALL
C     ALHA IS THE FRICTION ANGLE BETWEEN SOIL AND
C     REINFORCEMENT
C     ALHA IS ASSUMED TO BE 25 DEGREES
C     CR IS THE PROPORTION OF THE REINFORCEMENT, INCHES PER
C     FOOT OF WALL
      DIMENSION CR(4,100)
  301 READ 7,IH,IGA,IBA
    7 FORMAT(3I4)
      BETA=IBA
      BETA=BETA/57.2957
      PHI=IGA
      PHI=PHI/57.2957
      S=COS(BETA)
      T=COS(PHI)
      X=SQRT(S*S-T*T)
      CA1=S*(S-X)/(S+X)
      Y=S*T
      Z=(SIN(2.*PHI))*(SIN(PHI-BETA))/Y
      U=SQRT(Z)
      V=1.+U
      CA2=T/(V*V)
      PUNCH 17,IH,IGA,IBA
      PUNCH 27
      PUNCH 37
      DO 201 I=1,IH
      H=IH
      WL=I
      W1=H*WL
      W2=(WL*WL*(SIN(BETA)))/(2.*S)
      HX=H+(WL*(SIN(BETA))/S)
      PA2=HX*HX*CA2/2.
      PV2=PA2*(SIN(PHI))
      PH2=PA2*T
      TMO=(W1*WL/2.)+(2.*W2*WL/3.)+(PV2*WL)
      TMT=PH2*(H*S+WL*(SIN(BETA)))/(3.*S)
      IF(TMO-2.*TMT) 201,123,123
  123 DO 101 J=1,3
      D=J
      ALHA=25./57.2957
      E=H*H*S*(COS(ALHA))*CA1
      A=(H+D)/D
      B=(WL*H)+(WL*WL*SIN(BETA)/S)
      F=A*B*(SIN(ALHA))
      CR(J,I)=12.*E/F
```

```
      T=(SIN(CPH1))/T
      T=(SIN(ALPH-PH1))/((COS(ALPH))*T)
      P=WT*(V**2)*(C+(CP(J,I)*P))
      IF(P-1.0*PHP) 201,133,133
  133 GO TO 101
  101 CONTINUE
      PRINT 47,I,(CP(J,I),J=1,5)
  201 CONTINUE
   17 FORMAT(//16X7HBETA(FT) =I3,8X5HPHI =I3,8X6HBETA =I3)
   27 FORMAT(12X5HD(FT),10X1H1,17X1H2,17X1H3)
   37 FORMAT(7X6HWL(FT))
   47 FORMAT(5X,I3,6X,3F18.9)
      GO TO 301
```

APPENDIX B

LIST OF TABLES

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Table 1

K_r values, inches per foot of the wall

H(FT) = 10 PHI = 30 BETA = [illegible]

D(FT) / WL(FT)	1	2	3
5	1.559635900	2.850322600	[illegible]
6	1.299696600	2.362777300	[illegible]
7	1.114125700	2.042386500	[illegible]
8	.974772500	1.787062900	2.474422600
9	.866464440	1.588518100	2.199486800
10	.779817990	1.429666300	1.979538000

Table 2

K_r values, inches per foot of the wall

H(FT) = 10 PHI = 30 BETA = 10

D(FT) / WL(FT)	1	2	3
5	1.480940700	2.713408200	3.757026600
6	1.213700300	2.225117300	3.080931700
7	1.023986400	1.877308400	2.599359200
8	.882142520	1.617261200	2.239284800
9	.772194030	1.415689000	1.960184900
10	.684557190	1.255021500	1.737722100

Table 3

K_r values, inches per foot of the wall

H(FT) = 10 PHI = 30 BETA = 20

D(FT) / WL(FT)	1	2	3
5	1.540756600	2.824720300	[illegible]
6	1.245607600	2.283614000	[illegible]
7	1.036694200	1.900606000	2.631608400
8	.881536990	1.616151100	2.237747800
9	.762105330	1.397193100	1.934575100
10	.667591980	1.223918500	1.694656500

Table 4

K_r values, inches per foot of the wall

H(FT) = 10	PHI = 35	BETA = [illegible]	
D(FT)	1	2	3
WL(FT)			
6	1.[illegible]	1.[illegible]	2.[illegible]
7	.[illegible]	1.[illegible]	2.[illegible]
8	.792466640	1.452844500	2.011633900
9	.734409450	1.291417300	1.788116400
10	.683968500	1.162275500	1.[illegible]

Table 5

K_r values, inches per foot of the wall

H(FT) = 10	PHI = 35	BETA = 10	
D(FT)	1	2	3
WL(FT)			
6	.978373700	1.793685100	2.483564000
7	.825443740	1.513313500	2.095357200
8	.711102220	1.303667300	1.805105600
9	.622471860	1.141198400	1.580120900
10	.551827090	1.011683000	1.400791900

Table 6

K_r values, inches per foot of the wall

H(FT) = 10	PHI = 35	BETA = 20	
D(FT)	1	2	3
WL(FT)			
6	.967246280	1.773284900	2.455317500
7	.805419670	1.475869400	2.043511500
8	.684536110	1.254982800	1.737668600
9	.591794350	1.084956300	1.502247200
10	.518402310	.950404200	1.315944300

Table 7

K_r values, inches per foot of the wall

H(FT) = 10 PHI = 40 BETA = 10

D(FT) / WL(FT)	1	2	3
6	.780287740	1.430527500	1.980730300
7	.726710390	1.332302400	1.844726400
8	.635871580	1.165764500	1.614133600
9	.565219180	1.036235100	1.434787200
10	.508697260	.932611650	1.291308400

Table 8

K_r values, inches per foot of the wall

H(FT) = 10 PHI = 40 BETA = 10

D(FT) / WL(FT)	1	2	3
6	.780287740	1.430527500	1.980730300
7	.658320660	1.206921200	1.671121700
8	.567129250	1.039736900	1.439063700
9	.496443390	.910146200	1.260202500
10	.440101680	.806853080	1.117181200

Table 9

K_r values, inches per foot of the wall

H(FT) = 10 PHI = 40 BETA = 20

D(FT) / WL(FT)	1	2	3
6	.753060770	1.380611400	1.911615800
7	.626757370	1.149055100	1.590999500
8	.532953490	.977081380	1.352882000
9	.460748330	.844705280	1.169591900
10	.403608110	.739948170	1.024543600

Table 10

K_r values, inches per foot of the wall

H(FT) = 10 PHI = 45 BETA = 0

D(FT) / WL(FT)	1	2	3
6	.668977410	1.226458600	1.668173500
7	.573460200	1.051250200	1.429577200
8	.501733050	.919843930	1.250630100
9	.445984930	.817639040	1.112115600
10	.401386430	.735875130	1.001904000

Table 11

K_r values, inches per foot of the wall

H(FT) = 10 PHI = 45 BETA = 10

D(FT) / WL(FT)	1	2	3
6	.612903010	1.123655500	1.555830700
7	.517490910	.948016510	1.312638200
8	.445470570	.816696020	1.130809900
9	.389948010	.714904670	.989868070
10	.345692530	.633769650	.877527240

Table 12

K_r values, inches per foot of the wall

H(FT) = 10 PHI = 45 BETA = 20

D(FT) / WL(FT)	1	2	3
6	.581650670	1.066359500	1.476497800
7	.484096180	.887509660	1.228859500
8	.411643750	.754680180	1.044941800
9	.355873770	.652435250	.903371900
10	.311739680	.571522730	.791339190

Table 13

K_r values, inches per foot of the wall

H(FT) = 20 PHI = 30 BETA = 0

D(FT) / WL(FT)	1	2	3
7	1.167174500	2.228051200	3.196703200
8	1.021190200	1.949544900	2.797173200
9	.917724630	1.732928700	2.486377200
10	.816052160	1.559635900	2.237738500
11	.742683780	1.417850900	2.034387700
12	.680793460	1.299696600	1.864782100
13	.628424730	1.199719900	1.721337300
14	.583537250	1.114025600	1.598384600
15	.544634760	1.039757200	1.491623700
16	.510595090	.974772490	1.398586600
17	.480560080	.917432890	1.316310700
18	.453862300	.866464410	1.243188100
19	.429974810	.820861040	1.177757100
20	.408476070	.779817960	1.118869300

Table 14

K_r values, inches per foot of the wall

H(FT) = 20 PHI = 30 BETA = 10

D(FT) / WL(FT)	1	2	3
8	.985035910	1.880523000	2.698141800
9	.868435490	1.657922200	2.378758100
10	.775259420	1.480040700	2.123536600
11	.699117020	1.334678000	1.914972600
12	.635747790	1.213700400	1.741396100
13	.582202310	1.111477100	1.594728000
14	.536373800	1.023986300	1.469197900
15	.496717440	.948278770	1.360574000
16	.462074610	.882142480	1.265682700
17	.431559330	.823866030	1.182097300
18	.404482560	.772193970	1.107930500
19	.380300340	.726027940	1.041692300
20	.358577560	.684557160	.982190750

Table 15

K_r values, inches per foot of the wall

H(FT) = 20 PHI = 30 BETA = 20

D(FT) / WL(FT)	1	2	3
10	.807062950	1.540756600	2.210650600
11	.722968500	1.379448900	1.979203300
12	.652461100	1.245607600	1.787175000
13	.593408270	1.132870300	1.625422700
14	.543030270	1.036694100	1.487430800
15	.499582610	.953748630	1.368422000
16	.461757410	.881536880	1.264813800
17	.428554920	.818150330	1.173867800
18	.399198040	.762105290	1.093455500
19	.373073450	.712231150	1.021896800
20	.349691000	.667591910	.957849250

Table 16

K_r values, inches per foot of the wall

H(FT) = 20 PHI = 35 BETA = 0

D(FT) / WL(FT)	1	2	3
7	.948796420	1.811338500	2.598877100
8	.830196860	1.584921200	2.274017500
9	.737952760	1.408818800	2.021348900
10	.664157480	1.267936900	1.819213900
11	.603779520	1.152670000	1.653639900
12	.553464560	1.056614100	1.516011600
13	.510890360	.975336180	1.399395300
14	.474398190	.905669260	1.299438500
15	.442771640	.845291330	1.212809300
16	.415098410	.792460640	1.137008700
17	.390680860	.745845280	1.070125800
18	.368976360	.704409440	1.010674400
19	.349556560	.667335270	.957481030
20	.332078730	.633968490	.909607010

Table 17

K_r values, inches per foot of the wall

H(FT) = 20 PHI = 35 BETA = 10

D(FT) / WL(FT)	1	2	3
7	.915016180	1.746845000	2.[illegible]
8	.794145450	1.515904900	2.[illegible]
9	.700152900	1.336464500	1.[illegible]
10	.624042910	1.193072800	1.[illegible]
11	.563563910	1.075894800	1.543675000
12	.512481460	.978373770	1.403734600
13	.469318010	.895570800	1.285523200
14	.432375270	.825443750	1.184332300
15	.400407960	.764415220	1.096769700
16	.372482100	.711102220	1.020277100
17	.347883480	.664141220	.952898310
18	.326056670	.622471830	.893111780
19	.306563200	.585257020	.839716630
20	.289052280	.551827090	.791751940

Table 18

K_r values, inches per foot of the wall

H(FT) = 20 PHI = 35 BETA = 20

D(FT) / WL(FT)	1	2	3
8	.808270590	1.543062000	2.213958500
9	.707227870	1.350162200	1.937189300
10	.626705080	1.196437000	1.716626900
11	.561092980	1.071177500	1.536906800
12	.506652780	.967246270	1.387788000
13	.460796740	.879702880	1.262182400
14	.421676940	.805019600	1.155028200
15	.387938710	.740610280	1.062614700
16	.358566470	.684536000	.982160390
17	.332783890	.635314720	.911538490
18	.309987520	.591794310	.849096240
19	.289701100	.553065750	.793529120
20	.271544030	.518402240	.743794520

Table 19

K_r values, inches per foot of the wall

H(FT) = 20 PHI = 40 BETA = 6

D(FT) / WL(FT)	1	2	3
7	.761315670	1.453420700	2.088542800
8	.666151210	1.271743100	1.824675000
9	.592134400	1.131438300	1.621933400
10	.532920960	1.017394500	1.459740900
11	.484473500	.924964200	1.327036400
12	.444100790	.847828790	1.216459000
13	.409939190	.782611210	1.122876000
14	.380657820	.726710370	1.042671400
15	.355280630	.678263030	.973166030
16	.333075590	.635871610	.912337560
17	.313482910	.598467370	.858678660
18	.296067190	.565219190	.810966710
19	.280484700	.535470820	.768284220
20	.266460470	.508697260	.729870030

Table 20

K_r values, inches per foot of the wall

H(FT) = 20 PHI = 40 BETA = 10

D(FT) / WL(FT)	1	2	3
7	.729757870	1.393174000	1.998901900
8	.633279420	1.208987900	1.734634900
9	.558317030	1.066587900	1.529303100
10	.498414150	.951517960	1.365221300
11	.449462210	.858064290	1.231135600
12	.408722150	.780287790	1.119543300
13	.374297760	.714568500	1.025250400
14	.344834620	.658320670	.944547090
15	.319339560	.609648260	.874712810
16	.297067690	.567129250	.813707210
17	.277449420	.529676190	.759970210
18	.260041770	.496443370	.712288330
19	.244495020	.466763240	.669703810
20	.230529450	.440101680	.631450260

Table 21

K_r values, inches per foot of the wall

H(FT) = 20 PHI = 40 BETA = 20

D(FT) / WL(FT)	1	2	3
7	.730796960	1.395156600	2.[illegible]
8	.629288440	1.261268800	1.723[illegible]
9	.550626460	1.051184400	1.[illegible]
10	.487928510	.931499950	1.[illegible]
11	.436845440	.823977690	1.196576600
12	.394460400	.753060800	1.080472400
13	.358758650	.684902880	.982686810
14	.328301470	.626757350	.899260610
15	.302034180	.576610720	.827311060
16	.279166080	.532953440	.764672360
17	.259092750	.494631640	.709668860
18	.241344380	.460748320	.661073730
19	.225550150	.430595760	.617811300
20	.211413750	.403608080	.579089850

Table 22

K_r values, inches per foot of the wall

H(FT) = 20 PHI = 45 BETA = 0

D(FT) / WL(FT)	1	2	3
7	.600714440	1.146818400	1.645435100
8	.525625130	1.003466100	1.439755800
9	.467222330	.891969880	1.279782900
10	.420500100	.802772890	1.151804600
11	.382272810	.729793610	1.047095100
12	.350416740	.668977430	.959837220
13	.323461610	.617517640	.886003550
14	.300357210	.573409210	.822717590
15	.280333390	.535181940	.767869760
16	.262812550	.501733080	.719877930
17	.247352990	.472210350	.677532130
18	.233611160	.445984950	.639891480
19	.221315830	.422512070	.606212960
20	.210250040	.401366450	.575902330

Table 23

K_r values, inches per foot of the wall

H(FT) = 20 PHI = 45 BETA = 10

D(FT) / WL(FT)	1	2	3
7	.57321265	1.[illegible]	1.[illegible]
8	.49743043	.94[illegible]	1.[illegible]
9	.43854872	.83722935	1.[illegible]
10	.39149601	.74740150	1.[illegible]
11	.35[illegible]	.67[illegible]	.9[illegible]
12	.32[illegible]	.61[illegible]	.87[illegible]
13	.29[illegible]	.56128165	.80[illegible]
14	.27086185	.51709992	.74[illegible]
15	.25083590	.47866856	.68707234
16	.23334172	.44547058	.63915346
17	.21793189	.41605182	.59694304
18	.20425847	.38994800	.55940062
19	.19204677	.36663475	.52604118
20	.18107704	.34569254	.49599366

Table 24

K_r values, inches per foot of the wall

H(FT) = 20 PHI = 45 BETA = 20

D(FT) / WL(FT)	1	2	3
7	.56445384	1.0775936	1.5461126
8	.48605117	.92791584	1.3313575
9	.42528942	.81191615	1.1649231
10	.37686728	.71947394	1.0322886
11	.33741163	.64414949	.9242147
12	.30467417	.58165073	.8345422
13	.27749878	.52900677	.7590097
14	.25357420	.48409619	.6945728
15	.23328581	.44536383	.6390003
16	.21562290	.41164373	.5906192
17	.20011862	.38204465	.5481510
18	.18641009	.35587378	.5106015
19	.17421091	.33258448	.4771864
20	.16329221	.31173968	.4472786

Table 25

K_r values, inches per foot of the wall

H(FT) = 30 PHI = 30 BETA = 0

D(FT) / WL(FT)	1	2	3
11	.75466260	1.45215880	2.12673040
12	.69177405	1.34031220	1.94994310
13	.63856067	1.23721120	1.79958190
14	.59294919	1.14883900	1.67103860
15	.55341924	1.07224980	1.55963660
16	.51883054	1.00523410	1.46215880
17	.48831109	.94610275	1.37614940
18	.46118270	.89354149	1.29969670
19	.43690993	.84651299	1.23129160
20	.41516443	.80418735	1.16972710
21	.39529946	.76589270	1.11412570
22	.37733130	.73107940	1.06338820
23	.36092559	.69929334	1.01715390
24	.34588702	.67015612	.97477255
25	.33205154	.64334986	.93578162
26	.31928035	.61860564	.89979022
27	.30745513	.59569432	.86646447
28	.29647460	.57441953	.83551931
29	.28625133	.55461196	.80670830
30	.27670963	.53612489	.77981802

Table 26

K_r values, inches per foot of the wall

H(FT) = 30 PHI = 30 BETA = 10

D(FT) / WL(FT)	1	2	3
12	.66728242	1.29285960	1.88052310
13	.61258970	1.18689240	1.72638910
14	.56574408	1.09612920	1.59436970
15	.52517574	1.01752800	1.48064370
16	.48970718	.94880765	1.38006380
17	.45843798	.88822357	1.29196150
18	.43066787	.83441900	1.21370030
19	.40584398	.78632276	1.14374210
20	.38352403	.74307782	1.08084040
21	.36335000	.70399067	1.02398630
22	.34502897	.66849367	.97235436
23	.32831895	.63611798	.92526248
24	.31301829	.60647296	.88214247
25	.29895764	.57923043	.84251698
26	.28599368	.55411278	.80598218
27	.27400432	.53088338	.77219405
28	.26288496	.50933959	.74085763
29	.25254538	.48930667	.71171878
30	.24290741	.47063310	.68455724

Table 27

K_r values, inches per foot of the wall

H(FT) = 30 PHI = 30 BETA = 2

D(FT) / WL(FT)	1	2	3
15	.546720990	1.059279160	1.[illegible]
16	.507342510	.982976490	1.429782460
17	.472696170	.915648840	1.332143760
18	.441989760	.856355220	1.245617520
19	.414598690	.803284960	1.168414560
20	.390023290	.755670170	1.099155550
21	.367859230	.712727280	1.036694160
22	.347775730	.673815500	.980095260
23	.329499670	.638405590	.928589930
24	.312803440	.606056620	.881536930
25	.297495900	.576398310	.838397660
26	.283415480	.549117470	.798716340
27	.270424490	.523947440	.762106390
28	.258404960	.500659610	.728232170
29	.247255290	.479057130	.696810380
30	.236887480	.458969470	.667591970

Table 28

K_r values, inches per foot of the wall

H(FT) = 30 PHI = 35 BETA = 0

D(FT) / WL(FT)	1	2	3
10	.674869680	1.307560100	1.921905500
11	.613517890	1.188690900	1.729005000
12	.562391390	1.089633300	1.584921200
13	.519130520	1.005815300	1.463004200
14	.482049770	.933971430	1.358503900
15	.449913120	.871706680	1.267937000
16	.421793550	.817225020	1.188690900
17	.396982160	.769152940	1.118767900
18	.374927590	.726422220	1.056614100
19	.355194570	.688189480	1.001002800
20	.337434840	.653780010	.950952750
21	.321366510	.622647610	.905669280
22	.306758940	.594345450	.864502500
23	.293421590	.568504350	.826915430
24	.281195690	.544816670	.792460620
25	.269947870	.523023990	.760762180
26	.259565270	.502907690	.731502090
27	.249951730	.484281480	.704409420
28	.241024890	.466985710	.679251940
29	.232713680	.450882760	.655829460
30	.224956560	.435853330	.633966480

Table 29

K_r values, inches per foot of the wall

H(FT) = 30 PHI = 35 BETA = 10

D(FT) / WL(FT)	1	2	3
11	.590041440	1.143225200	1.662844000
12	.537901760	1.042184640	1.515274000
13	.493813520	.956763640	1.391086240
14	.456150880	.883598620	1.285234360
15	.423348410	.820237560	1.193072800
16	.394756920	.764841520	1.112496720
17	.369550570	.716004210	1.041463640
18	.347164850	.672631910	.978373680
19	.327154120	.633861140	.921970790
20	.309161820	.599001940	.871274260
21	.292809380	.567402580	.825443710
22	.278130640	.538878160	.783822720
23	.264660560	.512779850	.745861570
24	.252326580	.488882760	.711162180
25	.240992170	.466922330	.679159750
26	.230541820	.446674790	.649708760
27	.220877100	.427949390	.622471870
28	.211913690	.410582760	.597211330
29	.203578880	.394434070	.573722270
30	.195809630	.379381150	.551827140

Table 30

K_r values, inches per foot of the wall

H(FT) = 30 PHI = 35 BETA = 20

D(FT) / WL(FT)	1	2	3
12	.547538160	1.060855100	1.543662100
13	.500123290	.968988850	1.409438300
14	.459583960	.890443910	1.295191100
15	.42454216	.822559450	1.196437000
16	.393864490	.763306190	1.110263500
17	.367060720	.711180150	1.034443800
18	.343216420	.664981830	.967246290
19	.321946530	.623771400	.907303880
20	.302863100	.586797300	.853523290
21	.285652140	.553451040	.805019650
22	.270056790	.523235050	.761069150
23	.255864960	.495738340	.721073930
24	.242899900	.470618530	.684536080
25	.231013210	.447568090	.651037270
26	.220079400	.426403820	.620223760
27	.209991570	.406858650	.591794410
28	.200658090	.388775050	.565490990
29	.192000080	.372000170	.541091160
30	.183949210	.356401590	.518402320

Table 31

K_r values, inches per foot of the wall

H(FT) = 30 PHI = 40 BETA = 0

D(FT) / WL(FT)	1	2	3
9	.601684950	1.165764500	1.[illegible]
10	.541516450	1.049188100	1.[illegible]
11	.492287680	.953867410	1.[illegible]
12	.451263700	.874323460	1.271743200
13	.416551120	.807067780	1.173916800
14	.386797460	.749420090	1.[illegible]
15	.361010970	.699458760	1.[illegible]
16	.338447780	.655742590	.9[illegible]
17	.318539080	.617160480	.8[illegible]
18	.300842470	.582882290	.8[illegible]
19	.285008660	.552204280	.8[illegible]
20	.270758220	.524594870	.763045920
21	.257864970	.499613390	.726710460
22	.246143840	.476903690	.693678110
23	.235441930	.456166750	.663518190
24	.225631850	.437161720	.635871660
25	.216606570	.419675240	.610436720
26	.208275560	.403533890	.586958350
27	.200561640	.388588190	.565219190
28	.193398740	.374710040	.545032790
29	.186729810	.361789010	.526238550
30	.180505490	.349729370	.508697270

Table 32

K_r vlaues, inches per foot of the wall

H(FT) = 30 PHI = 40 BETA = 10

D(FT) / WL(FT)	1	2	3
9	.581573390	1.126798400	1.638979500
10	.520510400	1.008468900	1.466892900
11	.470578970	.911746750	1.326177100
12	.428995720	.831179200	1.208987900
13	.393833790	.763052920	1.109895100
14	.363716750	.704701220	1.025019900
15	.337635370	.654168530	.951517880
16	.314832640	.609988230	.887255630
17	.294729680	.571038740	.830601820
18	.276876280	.536447790	.780287700
19	.260917010	.505526730	.735311570
20	.246567510	.477724570	.694872110
21	.233597640	.452595450	.658320630
22	.221819050	.429774440	.625126410
23	.211076180	.408960110	.594851050
24	.201239390	.389901330	.567129200
25	.192199800	.372387110	.541653980
26	.183865280	.356238980	.518165770
27	.176157310	.341304810	.496443390
28	.169008680	.327454310	.476297210
29	.162361370	.314575150	.457563850
30	.156165120	.302560920	.440101700

Table 33

K_r values, inches per foot of the wall

H(FT) = 30 PHI = 4(BETA = 2(

D(FT) / WL(FT)	1	2	3
11	.470023770	.910671070	1.324612460
12	.426202160	.825941150	1.201368860
13	.389376760	.754417450	1.097334460
14	.357814400	.693265390	1.008280660
15	.330532200	.640406150	.931429860
16	.306725610	.594280850	.864468500
17	.285779360	.553697520	.805378210
18	.267215100	.517720280	.753066770
19	.250655190	.485644430	.706391510
20	.235797560	.456857810	.664520410
21	.222397770	.430895700	.626757340
22	.210255830	.407370690	.592539170
23	.199206620	.385962810	.561400440
24	.189112520	.366405490	.532953470
25	.179858000	.348474880	.506872590
26	.171345360	.331981620	.482882370
27	.163491360	.316764500	.460748370
28	.156224670	.302685300	.440269540
29	.149483880	.289625020	.421272770
30	.143215780	.277480570	.403608110

Table 34

K_r values, inches per foot of the wall

H(FT) = 30 PHI = 45 BETA = 0

D(FT) / WL(FT)	1	2	3
7	.610403350	1.182656500	1.720227600
8	.534102930	1.034824400	1.505199100
9	.474758150	.919843920	1.337954800
10	.427282340	.827859540	1.204159300
11	.388438490	.752599590	1.094690300
12	.356068610	.689882960	1.003466100
13	.328678720	.636815020	.926276420
14	.305201670	.591328240	.860113810
15	.284854890	.551906360	.802772890
16	.267051460	.517412210	.752599590
17	.251342550	.486976190	.708329020
18	.237379070	.459921960	.668977410
19	.224886540	.435715540	.633768070
20	.213641170	.413929770	.602079670
21	.203467780	.394218820	.573409210
22	.194219240	.376299780	.547345150
23	.185774920	.359938920	.523547540
24	.178034300	.344941470	.501733060
25	.170912930	.331143810	.481663720
26	.164339360	.318407510	.463138190
27	.158252710	.306614640	.445984930
28	.152600840	.295664120	.430056890
29	.147338730	.285468800	.415227350
30	.142427450	.275953170	.401386430

Table 35

K_r values, inches per foot of the wall

H(FT) = 30 PHI = 45 BETA = 20

D(FT) / WL(FT)	1	2	3
8	.516803140	1.001306190	1.456443270
9	.456816190	.885084380	1.287391100
10	.408852230	.792151210	1.152210980
11	.369631930	.716161860	1.041680390
12	.336068980	.652877400	.949639840
13	.309349870	.599365340	.871804160
14	.285693440	.553531050	.805136050
15	.265206950	.513838470	.747401420
16	.247295790	.479135580	.696924490
17	.231505240	.448541490	.652423880
18	.217481700	.421370790	.612902270
19	.204945960	.397082810	.577574970
20	.193674670	.375244680	.545810450
21	.183487040	.355506170	.517099870
22	.174235160	.337580650	.491026370
23	.165796820	.321231340	.467245570
24	.158070180	.306260990	.445470520
25	.150969740	.292503870	.425460170
26	.144423110	.279819780	.407010560
27	.138368630	.268089230	.389948090
28	.132753500	.257209900	.374123510
29	.127532150	.247093530	.359408770
30	.122665100	.237663620	.345692550

Table 36

K_r values, inches per foot of the wall

H(FT) = 30 PHI = 45 BETA = 20

D(FT) / WL(FT)	1	2	3
9	.453419750	.878500780	1.277819300
10	.403662510	.782096110	1.137594300
11	.363037960	.703386060	1.023106900
12	.329260440	.637942110	.927915820
13	.300747650	.582698560	.847561550
14	.276369450	.535465800	.778859370
15	.255297170	.494638270	.719473850
16	.236909380	.459011910	.667653680
17	.220730870	.427666070	.622059740
18	.206392170	.399884850	.581650680
19	.193601590	.375103080	.545604490
20	.182125820	.352868810	.513263690
21	.171776070	.332816140	.484096170
22	.162397850	.314645840	.457666670
23	.153863630	.298110780	.433615670
24	.146067130	.283005050	.411643730
25	.138919110	.269155770	.391499330
26	.132344090	.256416670	.372969710
27	.126277800	.244663240	.355873810
28	.120665140	.233768720	.340056320
29	.115458680	.223701190	.325383560
30	.110617310	.214321030	.311739690

Table 37

K_r values, inches per foot of the wall

H(FT) = 40 . PHI = 30 BLTA = 0

D(FT) / W (FT)	1	2	3
14	.597769888	1.167074500	1.7[illegible]
15	.557918580	1.089269500	1.[illegible]
16	.523048650	1.021190200	1.[illegible]
17	.492281080	.961122200	1.[illegible]
18	.464932160	.907724630	1.329922200
19	.440462040	.859949650	1.259926200
20	.418438930	.816952170	1.196929900
21	.398513260	.778049680	1.139933300
22	.380399020	.742683790	1.088118100
23	.363859920	.710393190	1.040886600
24	.348699110	.680793470	.997441680
25	.334751140	.653561730	.957543970
26	.321876100	.628424750	.920715370
27	.309954760	.605149750	.886614810
28	.298884940	.583537260	.854950010
29	.288578560	.563415340	.825468940
30	.278959290	.544634810	.797953330
31	.269960600	.527065940	.772212910
32	.261524320	.510595120	.748081230
33	.253599340	.495122930	.725412110
34	.246140540	.480560130	.704076470
35	.239107950	.466829830	.683959970
36	.232466070	.453862330	.664961100
37	.226183290	.441595770	.646989180
38	.220231010	.429974820	.629963130
39	.214584060	.418949850	.613810240
40	.209219450	.408476100	.598464990

Table 38

K_r values, inches per foot of the wall

H(FT) = 40 PHI = 3[illegible] BETA = 1[illegible]

D(FT) / HL(FT)	1	2	3
16	.504530630	.985036010	1.443192200
17	.472905060	.923290820	1.352728400
18	.446808450	.868435510	1.272359000
19	.419683460	.813381940	1.200489900
20	.397384110	.775259470	1.135845300
21	.376649540	.735363360	1.077302900
22	.358084330	.699117360	1.024287800
23	.341144600	.666044220	.975832300
24	.325626960	.635747870	.931444560
25	.311360650	.607894580	.890636310
26	.298201220	.582202370	.852994180
27	.286025510	.558430760	.818166000
28	.274728070	.536373880	.785850070
29	.264217950	.515854100	.755786250
30	.254416280	.496717530	.727746920
31	.245254450	.478830140	.701541840
32	.236672380	.462074670	.676993130
33	.228617290	.446348040	.653951800
34	.221042600	.431559370	.632284670
35	.213907060	.417628080	.611873710
36	.207174010	.404482590	.592614090
37	.200810740	.392059090	.574412140
38	.194788000	.380300380	.557184320
39	.189079520	.369155270	.540855420
40	.183661690	.358577580	.525357900

Table 39

K_r values, inches per foot of the wall

H(FT) = 40 PHI = 30 BETA = 20

D(FT) / WL(FT)	1	2	3
20	.413373710	.807062920	1.182441160
21	.390681660	.762759410	1.117531360
22	.370496080	.722568520	1.058646920
23	.351341220	.685951890	1.004999360
24	.334187410	.652461170	.955931440
25	.318441670	.621719480	.910891360
26	.303940820	.593408280	.869412150
27	.290545800	.567256110	.831096190
28	.278137470	.543030310	.795602560
29	.266613120	.520539380	.762637560
30	.255883800	.499582660	.731946670
31	.245871960	.480025760	.703308200
32	.236509900	.461757410	.676528390
33	.227737990	.444631340	.651436620
34	.219503740	.428554930	.627882810
35	.211760620	.413437400	.605733930
36	.204467260	.399198010	.584871520
37	.197586860	.385764840	.565190350
38	.191086400	.373073470	.546596010
39	.184936320	.361066160	.529003950
40	.179110010	.349690990	.512338010

Table 40

K_r values, inches per foot of the wall

H(FT) = 40 PHI = 3! BETA = 0

D(FT) / WL(FT)	1	2	3
13	.523351090	1.021780790	1.497927690
14	.485968870	.948796380	1.390097000
15	.453570960	.885543290	1.297423900
16	.425222770	.830196830	1.216334900
17	.400209660	.781361720	1.144785800
18	.377975810	.737952730	1.081186610
19	.358[illegible]82340	.699113120	1.024282000
20	.340178220	.664157460	.973067960
21	.323979250	.632530910	.926731420
22	.309252920	.603779510	.884607210
23	.295807140	.577528220	.846146050
24	.283481850	.553464550	.810889980
25	.272142580	.531325960	.778454350
26	.261675550	.510890350	.748513810
27	.251983860	.491968490	.720791080
28	.242984440	.474398180	.695048560
29	.234605660	.458039670	.671081340
30	.226785480	.442771670	.648711970
31	.219469820	.428488700	.627785790
32	.212611380	.415098420	.608167460
33	.206168610	.402519670	.589738160
34	.200104830	.390680880	.572392920
35	.194387550	.379518570	.556038820
36	.188987900	.368976380	.540593300
37	.183880110	.359004040	.525982680
38	.179041160	.349556560	.512141020
39	.174450360	.340593590	.499009200
40	.170089100	.332078740	.486533980

Table 41

K_r values, inches per foot of the wall

H(FT) = 40 PHI = 35 BETA = 10

D(FT) / WL(FT)	1	2	3
14	.468666820	.915016160	1.340605000
15	.435613720	.850483870	1.246057800
16	.406706210	.794045480	1.163368900
17	.381212590	.744272190	1.090445300
18	.358563680	.700052870	1.025658900
19	.338310220	.660510390	.967724600
20	.320092710	.624942910	.915614110
21	.303620230	.592782340	.868495130
22	.28865467[illegible]	.563563900	.825686680
23	.274999420	.536903620	.786626290
24	.262490520	.512481490	.750844980
25	.250990330	.490028730	.717940120
26	.240382410	.469318030	.687605490
27	.230567470	.450155550	.659530220
28	.221460510	.432375310	.633480090
29	.212988220	.415834150	.609245400
30	.205087020	.400408010	.586644260
31	.197701590	.385988840	.565518540
32	.190783520	.372482120	.545729630
33	.184290240	.359804760	.527155830
34	.178184230	.347883490	.509689770
35	.172432210	.336653370	.493236340
36	.167004640	.326056680	.477711000
37	.161875160	.316041990	.463038260
38	.157020180	.306563210	.449150780
39	.152418530	.297579050	.435987920
40	.148051170	.289052280	.423495240

Table 42

K_r values, inches per foot of the wall

H(FT) = 40 PHI = 35 BETA = 20

D(FT) / WL(FT)	1	2	3
16	.413992270	.808270600	1.184216400
17	.386569300	.754730530	1.105768000
18	.362238670	.707227910	1.036171100
19	.340511140	.664807450	.974020230
20	.320995300	.626705080	.918195900
21	.303374340	.592302270	.867791760
22	.287389110	.561093010	.822066550
23	.272825480	.532659260	.780407780
24	.259505110	.506652850	.742305310
25	.247278140	.482781150	.707330530
26	.236017850	.460796770	.675120860
27	.225616280	.440488940	.645367530
28	.215980880	.421676980	.617805820
29	.207031930	.404205200	.592207650
30	.198700340	.387938760	.568375390
31	.190925890	.372760100	.546136880
32	.183656010	.358566490	.525341670
33	.176844400	.345267650	.505857270
34	.170450290	.332783910	.487567130
35	.164437560	.321044760	.470367960
36	.158774080	.309987510	.454167750
37	.153431270	.299556310	.438884820
38	.148383500	.289701130	.424445840
39	.143607800	.280377150	.410785150
40	.139083520	.271544030	.397843620

Table 43

K_r values, inches per foot of the wall

H(FT) = 40 PHI = 40 BETA = 0

D(FT) / WL(FT)	1	2	3
11	.496289990	.968947120	1.419620200
12	.454932490	.888201530	1.301318500
13	.419937680	.819678350	1.201217100
14	.389942130	.761315610	1.115415900
15	.363946000	.710561230	1.041054800
16	.341199370	.666151150	.975988920
17	.321128820	.626965790	.918577810
18	.303288350	.592134350	.867545780
19	.287325800	.560969390	.821885410
20	.272959500	.532920920	.780791160
21	.259961430	.507543730	.743610640
22	.248144990	.484473560	.709810120
23	.237356080	.463409490	.678948830
24	.227466250	.444100760	.650659310
25	.218367600	.426336730	.624632910
26	.209968840	.409939170	.600608580
27	.202192220	.394756230	.578363820
28	.194971070	.380657800	.557707980
29	.188247920	.367531700	.538476650
30	.181973000	.355280630	.520527440
31	.176102900	.343819960	.503736240
32	.170599680	.333075580	.487994460
33	.165429990	.322982370	.473206760
34	.160564410	.313482910	.459288920
35	.155976850	.304526250	.446166360
36	.151644160	.296067180	.433772860
37	.147545670	.288065360	.422049270
38	.143662890	.280484690	.410942700
39	.139979230	.273292790	.400405710
40	.136479740	.266460470	.390395580

Table 44

K_r values, inches per foot of the wall

H(FT) = 40 PHI = 40 BETA = 10

D(FT) / WL(FT)	1	2	3
12	.439726240	.858513140	1.257821500
13	.404206840	.789169620	1.156225300
14	.373778410	.729757850	1.069180000
15	.347417400	.678291060	.993775310
16	.324362630	.633279440	.927827990
17	.304030560	.593583470	.869668830
18	.285967260	.558317000	.817999360
19	.269814400	.526780470	.771794700
20	.255285290	.498414150	.730234740
21	.242147910	.472764950	.692655680
22	.230212340	.449462210	.658514420
23	.219321790	.428199680	.627362380
24	.209345500	.408722170	.598825510
25	.200173690	.390815300	.572589890
26	.191713500	.374297780	.548389780
27	.183885740	.359015020	.525998750
28	.176622620	.344834650	.505222840
29	.169865660	.331642490	.485894820
30	.163564170	.319339590	.467869630
31	.157674030	.307839800	.451021100
32	.152156620	.297067700	.435238740
33	.146978000	.286957060	.420425470
34	.142108240	.277449430	.406495680
35	.137520800	.268493000	.393373480
36	.133192130	.260041770	.380991470
37	.129101180	.252054700	.369289440
38	.125229160	.244495030	.358213680
39	.121559180	.237329850	.347715830
40	.118076060	.230529450	.337752480

Table 45

K_r values, inches per foot of the wall

H(FT) = 40 PHI = 40 BETA = 20

D(FT) / FL(FT)	1	2	3
14	.374310140	.736796020	1.070701100
15	.346559020	.676615260	.991320010
16	.322318470	.629288420	.921980710
17	.300968000	.587604180	.860908500
18	.282625110	.550620470	.806723060
19	.265108880	.517593530	.758334710
20	.249914600	.487928490	.714872040
21	.236195600	.461143780	.675629310
22	.223750110	.436845460	.640029420
23	.212411430	.414708030	.607595500
24	.202040700	.394460440	.577930390
25	.192521250	.375874850	.550700370
26	.183754430	.358758660	.525623160
27	.175656160	.342947760	.502458360
28	.168154420	.328301490	.480999870
29	.161187100	.314698640	.461070110
30	.154700450	.302034210	.442515230
31	.148647560	.290216680	.425201190
32	.142987510	.279166090	.409010830
33	.137684250	.268812120	.393841030
34	.132706040	.259092760	.379601030
35	.128024760	.249953110	.366210410
36	.123615400	.241344360	.353597560
37	.119455690	.233223030	.341698850
38	.115525690	.225550160	.330457220
39	.111807510	.218290870	.319821530
40	.108285090	.211413750	.309745750

Table 46

K_r values, inches per foot of the wall

D(FT) = 40 PHI = 41 BETA = 0

BL(FT) \ D(FT)	1	2	3
10	.430756160	.641066130	1.232163000
11	.391596510	.764545570	1.120148200
12	.358963470	.700833430	1.026802500
13	.331356890	.646923180	.947817730
14	.307682970	.600714380	.880116440
15	.287170780	.560666750	.821442020
16	.269222600	.525625080	.770101880
17	.253385980	.494705960	.724801780
18	.239308990	.467222290	.684535060
19	.226713780	.442631640	.648506850
20	.215378090	.420500060	.616081520
21	.205121980	.400476250	.586744320
22	.195798250	.382272780	.560074100
23	.187285280	.365652220	.535723060
24	.179481740	.350416710	.513401280
25	.172302470	.336400050	.492865200
26	.165675450	.323461590	.473908860
27	.159539320	.311481530	.456356680
28	.153841480	.300357190	.440058240
29	.148536600	.290000070	.424883800
30	.143585390	.280333390	.410721010
31	.138953600	.271290370	.397471950
32	.134611300	.262812540	.385050940
33	.130532170	.254848520	.373382740
34	.126692990	.247352990	.362400900
35	.123073180	.240285760	.352046570
36	.119654490	.233611150	.342267510
37	.116420580	.227297330	.333017040
38	.113356880	.221315820	.324253420
39	.110450290	.215641070	.315939240
40	.107689040	.210250040	.308040760

Table 47

K_r values, inches per foot of the wall

H(FT) = 40 PHI = 45 BETA = 10

D(FT) / WL(FT)	1	2	3
11	.37838157	.73874498	1.06234736
12	.34539762	.67434775	.98799787
	.31749923	.61987957	.90819569
14	.29359674	.57321262	.83982312
15	.27289057	.53278631	.78059393
16	.25478144	.49743043	.72879341
17	.23881093	.46624992	.68311036
18	.22462251	.43854869	.64252485
19	.21193471	.41377727	.60623186
20	.20052234	.39149600	.57358720
21	.19020314	.37134898	.54406948
22	.18082795	.35304507	.51725209
23	.17227361	.33634371	.49278268
24	.16443740	.32104444	.47036745
25	.15723310	.30697890	.44975981
26	.15058775	.29400466	.43075102
27	.14443918	.28200031	.41316324
28	.13873412	.27086187	.39684412
29	.13342664	.26049964	.38166227
30	.12847693	.25083592	.36750379
31	.12385032	.24180302	.35426955
32	.11951649	.23334172	.34187277
33	.11544877	.22539998	.33023720
34	.11162365	.21793190	.31929557
35	.10802030	.21089678	.30898830
36	.10462019	.20425847	.29926245
37	.10140682	.19798476	.29007070
38	.09836542	.19204677	.28137087
39	.09548271	.18641863	.27312499
40	.09274678	.18107704	.26529894

Table 48

K_r values, inches per foot of the wall

H(FT) = 40 PHI = 45 BETA = 20

D(FT) / FL(FT)	1	2	3
12	.342829550	.669333910	.980652000
13	.313883110	.612819390	.897851680
14	.289110450	.564453770	.826990290
15	.267675980	.522605520	.765677830
16	.248953020	.486051110	.712121400
17	.232462290	.453854950	.664950310
18	.217831150	.425280390	.623098450
19	.204765360	.39977998C	.585724160
20	.193029570	.376867230	.552154370
21	.182433250	.356179200	.521843990
22	.172820580	.337411610	.494347270
23	.164062790	.320313060	.469295890
24	.156052620	.304674180	.446383090
25	.148699970	.290319000	.425351110
26	.141928630	.277098760	.405981920
27	.135673670	.264886710	.388089840
28	.129879460	.253574190	.371515690
29	.124498030	.243067590	.356122300
30	.119487850	.233285820	.341790840
31	.114812710	.224158170	.328417780
32	.110440990	.215622890	.315912640
33	.106344850	.207625670	.304195760
34	.102499770	.200118610	.293197040
35	.098884037	.193059310	.282854370
36	.095478323	.186410060	.273112420
37	.092265440	.180137290	.263922080
38	.089229978	.174210910	.255239240
39	.086358126	.168603960	.247024430
40	.083637466	.163292190	.239242070

Table 49

K_r values, inches per foot of the wall

H(FT) = 50 PHI = 30 BETA = 0

D(FT) / WL(FT)	1	2	3
18	.467211240	.916452790	1.348741900
19	.442621180	.868218460	1.277755500
20	.420490120	.824807570	1.213867700
21	.400466770	.785530980	1.156064500
22	.382263740	.749825050	1.103516100
23	.365643570	.717223930	1.055537100
24	.350408420	.687339620	1.011556400
25	.336392090	.659846010	.971094190
26	.323453930	.634467330	.933744420
27	.311474150	.610968560	.899161350
28	.300350070	.589148230	.867048380
29	.289993170	.568832790	.837150180
30	.280326730	.549871680	.809245190
31	.271283930	.532133890	.783140520
32	.262806310	.515504690	.758667330
33	.254842480	.499883350	.735677430
34	.247347120	.485180910	.714039870
35	.240280060	.471318580	.693638740
36	.233605610	.458226410	.674371010
37	.227291950	.445841900	.656144730
38	.221310580	.434109230	.638877770
39	.215635950	.422978210	.622496300
40	.210245050	.412403760	.606933860
41	.205117120	.402345120	.592130610
42	.200233380	.392765490	.578032270
43	.195576790	.383631410	.564589670
44	.191131860	.374912510	.551758060
45	.186884490	.366581120	.539496780
46	.182821780	.358611960	.527768590
47	.178931960	.350981920	.516539450
48	.175204210	.343669790	.505778220
49	.171628610	.336656130	.495456220
50	.168196040	.329923000	.485547100

Table 50

K_r values, inches per foot of the wall

H(FT) = 50 PHI = 30 BETA = 10

D(FT) / WL(FT)	1	2	3
20	.405603060	.795606010	1.170891800
21	.385420260	.755232110	1.111473600
22	.366316610	.718544120	1.057480000
23	.349246840	.685061100	1.008263100
24	.333606670	.654382310	.963052260
25	.319224470	.626171100	.921534860
26	.305955070	.600142680	.883228910
27	.293674720	.576054270	.847778030
28	.282277420	.553698020	.814876360
29	.271671760	.532894620	.784260030
30	.261778510	.513488630	.755700340
31	.252528690	.495344750	.728997980
32	.243861930	.478344560	.703978840
33	.235725180	.462384010	.680489730
34	.228071620	.447371260	.658395510
35	.220859810	.433225010	.637575460
36	.214052880	.419872980	.617926280
37	.207617990	.407250660	.599350050
38	.201525700	.395300390	.581762880
39	.195749630	.383970430	.565088570
40	.190266030	.373214120	.549258570
41	.185053470	.362989490	.534210970
42	.180092560	.353258480	.519889890
43	.175365710	.343986570	.506244420
44	.170856930	.335142430	.493228510
45	.166551640	.326697450	.480800060
46	.162436580	.318625590	.468920700
47	.158499540	.310902940	.457555310
48	.154729390	.303507650	.446671670
49	.151115870	.296419600	.436240200
50	.147649590	.289620340	.426233740

Table 51

K_r values, inches per foot of the wall

H(FT) = 50 PHI = 30 BETA = 20

D(FT) / WL(FT)	1	2	3
24	.348311810	.683227030	1.005504000
25	.332320010	.651858480	.959339030
26	.317582600	.622950510	.916795160
27	.303959770	.596228810	.877468840
28	.291331690	.571458320	.841014170
29	.279595070	.548436510	.807133010
30	.268660450	.526987820	.775567030
31	.258449820	.506959260	.746091040
32	.248895050	.488217200	.718506350
33	.239936170	.470644000	.692645910
34	.231520300	.454135990	.668351110
35	.223600710	.438601370	.645488840
36	.216135680	.423958440	.623938900
37	.209088180	.410134520	.603594220
38	.202425000	.397064400	.584358970
39	.196116330	.384689720	.566147170
40	.190135390	.372957880	.548881450
41	.184458010	.361821480	.532492000
42	.179062290	.351237560	.516915680
43	.173928410	.341167260	.502095230
44	.169038330	.331575180	.487978600
45	.164375630	.322429140	.474516380
46	.159925350	.313699720	.461671300
47	.155673730	.305360020	.449397790
48	.151608250	.297385410	.437661560
49	.147717340	.289753240	.426429310
50	.143990400	.282442710	.415670420

Table 52

K_r values, inches per foot of the wall

H(FT) = 50 PHI = 31 BETA = 0

D(FT) / WL(FT)	1	2	3
16	.427307190	.838179500	1.233547360
17	.402171490	.788874820	1.160985660
18	.379828630	.745048440	1.096486400
19	.359837650	.705835390	1.038776600
20	.341845760	.670543640	.986837790
21	.325567390	.638612960	.939845520
22	.310768870	.609585120	.897125290
23	.297257180	.583081390	.858119850
24	.284871460	.558786350	.822364830
25	.273476600	.536434870	.789470250
26	.262958270	.515802780	.759106010
27	.253219080	.496698990	.730991020
28	.244175540	.478959720	.704884140
29	.235755690	.462443880	.680577810
30	.227897170	.447029070	.657891900
31	.220545640	.43260878[illegible]	.636669590
32	.213653590	.419089750	.616773630
33	.207179240	.406390070	.598083530
34	.201085740	.394437430	.580492850
35	.195340430	.383167770	.563907250
36	.189914310	.372524230	.548243260
37	.184781490	.362456000	.533425850
38	.179918820	.352917690	.519388330
39	.175305510	.343868510	.506070690
40	.170922880	.335271800	.493418900
41	.166754020	.327094430	.481384300
42	.162783690	.319306480	.469922780
43	.158998020	.311880750	.458994350
44	.155384430	.304792540	.448562640
45	.151931440	.298019380	.438594580
46	.148628590	.291540690	.429059920
47	.145466270	.285337700	.419930970
48	.142435730	.279393160	.411182420
49	.139528880	.273691270	.402790940
50	.136738300	.268217430	.394735130

Table 53

K_r values, inches per foot of the wall

H(FT) = 50 PHI = 3! BETA = 10

D(FT) / WL(FT)	1	2	3
18	.365698120	.717320940	1.055694600
19	.345305800	.677320610	.996826230
20	.326959900	.641344430	.943865290
21	.310367940	.608798710	.895967980
22	.295290770	.579224210	.852443210
23	.281530700	.552233280	.812720740
24	.268923030	.527502860	.776325010
25	.257329420	.504761580	.742856690
26	.246632850	.483779860	.711977960
27	.236733570	.464362000	.683400720
28	.227546110	.446340440	.656878430
29	.218996800	.429570660	.632198340
30	.211021770	.413927330	.609176150
31	.203565410	.399301400	.587651160
32	.196579070	.385597420	.567483030
33	.190019970	.372731480	.548548270
34	.183850370	.360629590	.530737940
35	.178036870	.349226180	.513955530
36	.172549750	.338463000	.498115370
37	.167362540	.328288050	.483140920
38	.162451490	.318654840	.468963750
39	.157795350	.309521660	.455522460
40	.153374980	.300850920	.442761770
41	.149173090	.292608760	.430631780
42	.145174070	.284764520	.419087440
43	.141363710	.277290350	.408087720
44	.137729150	.270161020	.397595490
45	.134258620	.263353450	.387576810
46	.130941430	.256846660	.378000770
47	.127767760	.250621370	.368839030
48	.124728610	.244659970	.360065640
49	.121815730	.238946240	.351656750
50	.119021530	.233465290	.343590460

Table 54

K_r values, inches per foot of the wall

H(FT) = 50 PHI = 3! BETA = 20

D(FT) / PL(FT)	1	2	3
20	.332817300	.652833970	.960774530
21	.314967450	.617820790	.909245710
22	.298764310	.586037730	.862470600
23	.283992620	.557062460	.819827820
24	.270473080	.530543370	.780799760
25	.258055040	.506184880	.744951440
26	.246611060	.483737100	.711915030
27	.236032580	.462987010	.681377130
28	.226226550	.443752090	.653069140
29	.217112760	.425875060	.626759550
30	.208621750	.409219600	.602247750
31	.200692930	.393666910	.579358890
32	.193273410	.379113220	.557940220
33	.186316610	.365467180	.537857370
34	.179781470	.352648280	.518991830
35	.173631700	.340585250	.501238600
36	.167834910	.329214640	.484504610
37	.162362350	.318480010	.468706440
38	.157188220	.308330720	.453769770
39	.152289370	.298721460	.439627840
40	.147645020	.289611390	.426220570
41	.143236390	.280963690	.413493740
42	.139046470	.272745000	.401398330
43	.135059880	.264925150	.389889860
44	.131262610	.257476660	.378927930
45	.127641910	.250374520	.368475730
46	.124186150	.243595900	.358499640
47	.120884660	.237119910	.348968940
48	.117727700	.230927420	.339855460
49	.114706310	.225000840	.331133330
50	.111812250	.219324030	.322778770

Table 55

K_r values, inches per foot of the wall

H(FT) = 50 PHI = 46 BETA = 0

H(FT)	D(FT) 1	2	3
14	.391853630	.668635970	1.131200160
15	.365730050	.617393570	1.055786800
16	.342871920	.572556470	.989809180
17	.322703000	.532994330	.931576600
18	.304775060	.497827970	.879822370
19	.288734260	.466363360	.833515930
20	.274297550	.438045210	.791846110
21	.261235760	.412423990	.754133440
22	.249361400	.389132000	.719854660
23	.238519600	.367865370	.688556640
24	.228581280	.348371000	.659866760
25	.219438030	.330436140	.633472100
26	.210998110	.313880910	.609107790
27	.203183360	.298552000	.586548280
28	.195926810	.284317990	.565600080
29	.189170720	.271065650	.546095640
30	.182865020	.258696790	.527893430
31	.176966150	.247125930	.510864620
32	.171435960	.236278230	.494900070
33	.166240930	.226087990	.479903110
34	.161351490	.216497180	.465788320
35	.156741450	.207454390	.452480090
36	.152387520	.198914000	.439911210
37	.148268940	.190835230	.428021690
38	.144367120	.183181680	.416757970
39	.140665400	.175920600	.406071870
40	.137148770	.169022590	.395920060
41	.133803680	.162461060	.386263480
42	.130617870	.156211990	.377066730
43	.127580250	.150253560	.368297740
44	.124680700	.144565990	.359927320
45	.121910010	.139131190	.351928940
46	.119259800	.133932680	.344278320
47	.116722350	.128955400	.336953230
48	.114290640	.124185490	.329933380
49	.111958180	.119610280	.323200050
50	.109719010	.115218070	.316736050

Table 56

K_r values, inches per foot of the wall

B(FT) = 50 PHI = 40 BETA = 10

D(FT) / WL(FT)	1	2	3
15	.353505400	.673414410	1.020496700
16	.330304990	.647905950	.953522030
17	.309640970	.607765000	.894446670
18	.291657230	.572096880	.841953910
19	.275393620	.540195190	.795004290
20	.260762120	.511494940	.752766140
21	.247529450	.485538570	.714566170
22	.235504870	.461951860	.679853700
23	.224530720	.440425640	.648173620
24	.214475660	.420702250	.619146740
25	.205229340	.402565270	.592454570
26	.196698450	.385831600	.567827680
27	.188803420	.370345170	.545036320
28	.181476090	.355972340	.523883850
29	.174657710	.342597840	.504200610
30	.168297350	.330121730	.485839590
31	.162350640	.318457040	.468672650
32	.156778780	.307527620	.452587850
33	.151547660	.297266580	.437486700
34	.146627200	.287614890	.423282330
35	.141990720	.278520270	.409897770
36	.137614550	.269936250	.397264680
37	.133477560	.261821360	.385322020
38	.129560830	.254138540	.374015230
39	.125847390	.246854510	.363295320
40	.122321990	.239939280	.353118220
41	.118970830	.233365860	.343444120
42	.115781470	.227109800	.334237100
43	.112742580	.221148890	.325464430
44	.109843890	.215463000	.317096510
45	.107076010	.210033720	.309106250
46	.104430440	.204844320	.301469020
47	.101899320	.199879430	.294162210
48	.099475498	.195125010	.287165120
49	.097152367	.190568100	.280458730
50	.094923892	.186196850	.274025580

Table 57

K_r values, inches per foot of the wall

H(FT) = 50 PHI = 40 BETA = 20

D(FT) / FL(FT)	1	2	3
17	.310769760	.609586880	.897127870
18	.291615760	.572015560	.841834240
19	.274500850	.538444010	.792427020
20	.259118760	.508271430	.748022120
21	.245221550	.481011520	.707903760
22	.232606400	.456266450	.671486450
23	.221105740	.433707410	.638286420
24	.210579950	.413060670	.607909680
25	.200911730	.394096090	.579990560
26	.192001890	.376619110	.554269670
27	.183765890	.360463890	.530494040
28	.176131300	.345488320	.508454530
29	.169035650	.331569950	.487970890
30	.162424870	.318602650	.468886950
31	.156251800	.306493920	.451066560
32	.150475250	.295162980	.434390800
33	.145058950	.284538690	.418755070
34	.139970940	.274558390	.404067090
35	.135182970	.265166580	.390245180
36	.130669810	.256313660	.377216660
37	.126409080	.247956290	.364916820
38	.122380710	.240054450	.353287700
39	.118566650	.232573050	.342277340
40	.114950740	.225480290	.331838950
41	.111518350	.218747530	.321930330
42	.108256240	.212348770	.312513310
43	.105152430	.206260540	.303553260
44	.102196020	.200461430	.295018720
45	.099377086	.194931970	.286881040
46	.096686564	.189654400	.279114040
47	.094116151	.184612450	.271693800
48	.091658269	.179791210	.264598390
49	.089305928	.175177010	.257807680
50	.087052720	.170757260	.251303140

Table 58

K_r values, inches per foot of the wall

H(FT) = 50 PHI = 45 BETA = 0

D(FT) / W (FT)	1	2	3
12	.260723110	.407572250	1.041332880
13	.332975170	.653143610	.961230340
14	.309191230	.606490530	.892570970
15	.288578480	.566057790	.833066260
16	.270542320	.530679180	.780999620
17	.254628080	.499462760	.735056440
18	.240482080	.471714830	.694221870
19	.227825120	.446887740	.657683890
20	.216433870	.424543370	.624799670
21	.206127490	.404327000	.595047310
22	.196758060	.385948510	.567999710
23	.188203360	.369168130	.543304080
24	.180361550	.353786130	.520666390
25	.173147090	.339634670	.499839740
26	.166487580	.326571810	.480615140
27	.160321380	.314476570	.462814610
28	.154595610	.303245250	.446285480
29	.149264730	.292788520	.430896340
30	.144289240	.283028900	.416533140
31	.139634750	.273898940	.403096590
32	.135271160	.265339590	.390499800
33	.131172030	.257299000	.378666480
34	.127314040	.249731390	.367529230
35	.123676490	.242596200	.357028410
36	.120241030	.235857420	.347110960
37	.116991270	.229482890	.337729560
38	.113912560	.223443870	.328841940
39	.110991720	.217714530	.320410100
40	.108216930	.212271670	.312399840
41	.105577490	.207094310	.304780330
42	.103063740	.202163500	.297523660
43	.100666910	.197462020	.290604510
44	.098379029	.192974250	.283999850
45	.096192828	.188685930	.277688750
46	.094101680	.184584060	.271652040
47	.092099516	.180656740	.265872200
48	.090180776	.176893060	.260333200
49	.088340352	.173283000	.255020280
50	.086573545	.169817330	.249919870

Table 59

K_r values, inches per foot of the wall

H(FT) = 50 PHI = 45 DELTA = 10

D(FT) / HL(FT)	1	2	3
13	.322592170	.632698460	.921141150
14	.298506170	.585521320	.861725390
15	.277672600	.544665470	.801582180
16	.259449070	.508919340	.748975670
17	.243374920	.477380280	.702572960
18	.229091890	.449372570	.661340770
19	.216317100	.424314330	.624462630
20	.204824300	.401770750	.591285260
21	.194430260	.381382460	.561279820
22	.184985150	.362855490	.534013760
23	.176365140	.345947000	.509129580
24	.168467060	.330454610	.486329450
25	.161204230	.316208310	.465363200
26	.154503360	.303064290	.446019190
27	.148301940	.290899960	.428116950
28	.142546450	.279610340	.411502040
29	.137190730	.269104900	.396041180
30	.132194760	.259305120	.381618910
31	.127523720	.250142700	.368134560
32	.123147120	.241557820	.355500220
33	.119038170	.233497950	.343638520
34	.115173220	.225916710	.332481220
35	.111531350	.218773030	.321967870
36	.108093940	.212030430	.312044790
37	.104844400	.205656320	.302664030
38	.101767870	.199621590	.293782730
39	.098851034	.193900100	.285362420
40	.096081890	.188468310	.277368480
41	.093449613	.183305000	.269769640
42	.090944420	.178390970	.262537670
43	.088557420	.173708770	.255646890
44	.086280546	.169242590	.249074030
45	.084106430	.164977990	.242797810
46	.082028374	.160901800	.236798890
47	.080040222	.157001970	.231059520
48	.078136347	.153267440	.225563420
49	.076311567	.149688070	.220295660
50	.074561137	.146254530	.215242530

Table 60

K_r values, inches per foot of the wall

H(FT) = 50 PHI = 45 BETA = 20

D(FT) / SL(FT)	1	2	3
15	.275608080	.540615870	.755623360
16	.256697910	.503522830	.741033630
17	.240033010	.470834010	.692925530
18	.225238800	.441814600	.650217720
19	.212019550	.415884530	.612056470
20	.200138690	.392579770	.577758920
21	.189404740	.371524700	.546772210
22	.179661030	.352412050	.518644140
23	.170778120	.334987850	.493001030
24	.162648190	.319040680	.469531620
25	.155180630	.304392780	.447974340
26	.148298830	.290893870	.428107990
27	.141937490	.278415860	.409744110
28	.136040670	.266849000	.392721190
29	.130560120	.256098700	.376900000
30	.125454070	.246082990	.362159900
31	.120686100	.236730430	.348395750
32	.116224390	.227978610	.335515690
33	.112040940	.219772600	.323438930
34	.108111050	.212064900	.312094200
35	.104412910	.204800930	.301418400
36	.100927030	.197972250	.291355410
37	.097636120	.191517010	.281855230
38	.094524674	.185413770	.272873110
39	.091578766	.179635260	.264368900
40	.088785899	.174156950	.256306470
41	.086134780	.168956680	.248653230
42	.083615186	.164014400	.241379690
43	.081217863	.159311950	.234459110
44	.078934385	.154832820	.227867190
45	.076757085	.150561970	.221581780
46	.074678974	.146485670	.215582700
47	.072693633	.142591350	.209851440
48	.070795209	.138867520	.204371070
49	.068978302	.135303590	.199126040
50	.067237965	.131889850	.194102060

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ANALYSIS OF A RETAINING WALL CONSTRUCTED OF STRAP REINFORCED EARTH

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ABSTRACT

The object of this report is to suggest an elementary way to analyse and design a retaining wall constructed of strap reinforced earth.

In this analysis, based on the principle of reinforced earth, the soil is assumed to be cohesionless. The stresses developed in the reinforced earth depend on the sum of the contact actions between the soil and the reinforcement. As a result, if the reinforcements are properly placed and designed, a stable reinforced earth body can be built up.

The principle of reinforced earth is used to set up a series of tables which indicate to the retaining wall designer the proportions of the reinforcement to the earth mass.

The procedure of analysis and design of a retaining wall constructed of reinforced earth is presented in part III.