INTERACTION OF RETAINING WALLS WITH SOIL

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ABSTRACT

The paper considers the interaction between rigid retaining walls and the soil retained by them as well as the soil supporting them. Finite element method is employed for the non-linear two dimensional retaining wall-soil interaction analysis. The constitutive relationship of soil has been formulated by a set of spline functions representing octahedral shear stress and octahedral shear strain of soil. A study of the stresses and strains in the soil has revealed that the extent of soil to be included in the finite element mesh need not be very large for faithful prognosis. A planned scheme of analyses of a number of rigid retaining walls with varying heights, thickness of the stem, thickness of the wall footing etc. have been examined. The effect of unit weight, slope of backfill soil, etc. on the lateral soil force and stresses in the walls have been studied. Analyses have also been carried out for various surcharge loads. Finally, results of the finite element analyses have been compared with a few commonly used methods.

KEYWORDS

Soil, Retaining wall, Finite element, Interaction, Spline functions, Non-linear

INTRODUCTION

The paper studies the interaction between rigid retaining walls and soil by conducting non-linear finite element (FE) analyses of the system. The constitutive relationship of soil has been formulated by a set of spline functions representing the octahedral shear stress and octahedral shear strain of soil. A planned scheme of analyses of a number of rigid retaining walls with varying heights, thickness of the stem, thickness of the wall footing, etc. have been examined. The effect of unit weight of soil, various types of surcharge loads, slope of backfill material etc. on the lateral soil force and stresses in the walls have been studied. A detailed description of the study is available elsewhere in Ahmed (1993).

CHARACTERISATION OF SOIL RESPONSE

Poor representation of the stress-strain characteristics of soil can lead to calculated modes of behaviour which are completely different from actual ones. Assumption of linear elastic behaviour of soil is unrealistic, because soils never behave as a linear elastic material (Rahman, 1978). Non-linear elastic soil models have been found to provide an expedient, and often satisfactory means for solving many geotechnical engineering problems. Again, the cubic spline function usually provides better simulation of stress-strain curves in comparison to other functional relationships for non-linear elastic model (Desai, 1971, 1974; Leonard and Roy, 1976; Rahman, 1978). On the other hand plasticity models of soil usually produce unsymmetric stress-strain matrix and do not assure uniqueness and stability of solution. Considering these the non-linear elastic model has been selected for the present study.

FINITE ELEMENT MODELLING OF THE RETAINING WALL - SOIL SYSTEM

In case of retaining wall-soil system, construction of the analytical model considers the structural constitutive model, soil constitutive model, simulation of footing shape, wall size, non-linearity of soil, boundary conditions, etc. Considering all the above mentioned aspects of the retaining wall-soil system, a FE computer program of Seraj (1986) has been adapted so that these aspects representing the field behaviour are included.

To represent the retaining wall, beam element having three degrees of freedom (horizontal and vertical displacement and a rotation in its plane) at each node, was used. Four noded isoparametric elements with two degrees of freedom (horizontal and vertical displacement) at each node was used to represent the soil. To simulate the non-linear characteristics of soil, spline function has been used adopting subroutines of Rahman (1978).

Figure 1 shows configuration of the finite element mesh of retaining wall-soil systems considered. The bottom boundary was restrained from vertical displacement but could move horizontally. The lateral boundaries were restrained against horizontal movement but they were free to displace vertically. Nodes at the surface of soil were allowed to move vertically as well as horizontally. Nodes representing the wall were allowed to move vertically, horizontally and rotate in its own plane.

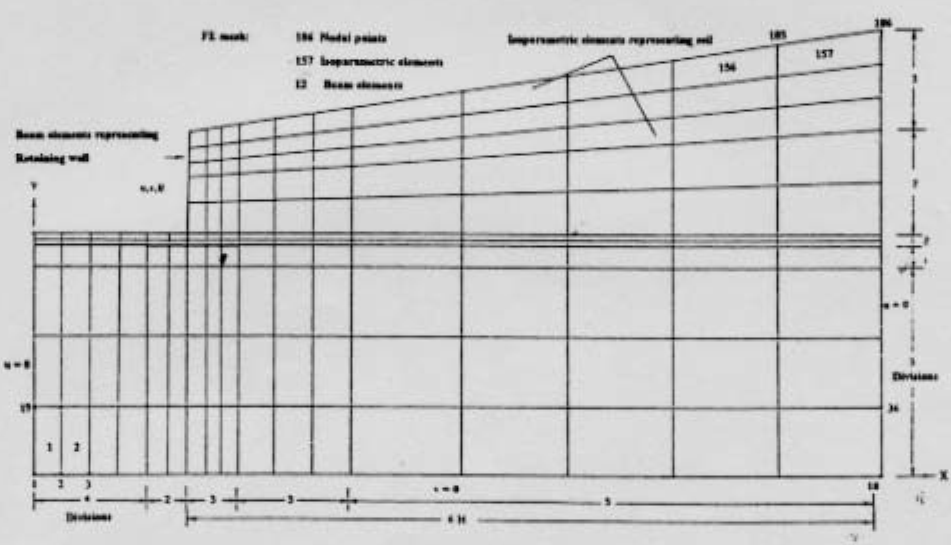
In the retaining wall-soil system, the effect of loading or disturbance in soil decreases with increasing distance from the wall. Accordingly, there should be an optimum distance from the wall after which the soil and load will have no effect on the wall. Similarly, the extent of soil below the wall footing should be large enough to simulate infinite depth of homogeneous soil mass. Here, the horizontal and vertical extents of soil to be included in the FE mesh has been fixed on the basis of analysis results shown in Figures 2 and 3.

It is clear from these figures that a horizontal extent of soil (retained) equal to six times the wall height and a vertical extent of soil below the footing equal to about three times the footing width may be considered to be adequate for modelling a retaining wall-soil system. The stress-strain curves at two nodes along the retaining wall centre line are shown in Figure 4. The soil below the wall footing is found to be highly strained in comparison to the soil at a greater depth but at the same stress level. This is because soil elements become stiffer with the increase in depth having a higher value of confining stress. This also points out clearly that contribution of soil at great depth to the deformation of structure is minimal.

PARAMETRIC STUDY

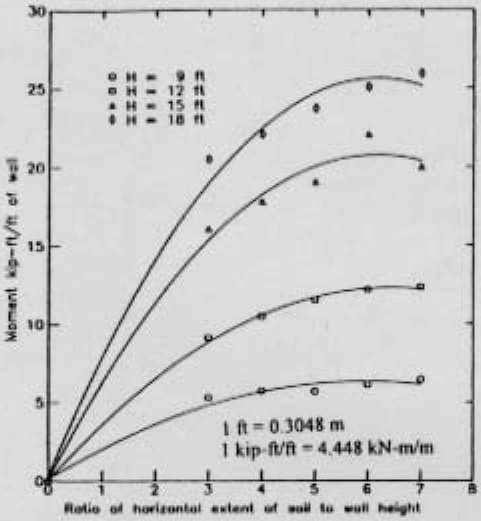
In order to understand in detail the variation of forces on retaining walls under various conditions, it is essential to conduct a systematic parametric study. The various parameters considered in the present study for understanding the interaction behaviour of retaining wall-soil system, with there range is shown Table 1.

Figure 1



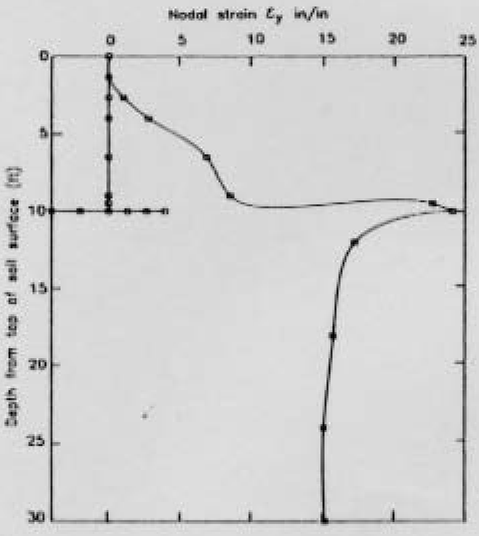
Finite element mesh of retaining wall-soil system

Figure 2



Variation of moment at wall base with horizontal extent of soil

Figure 3

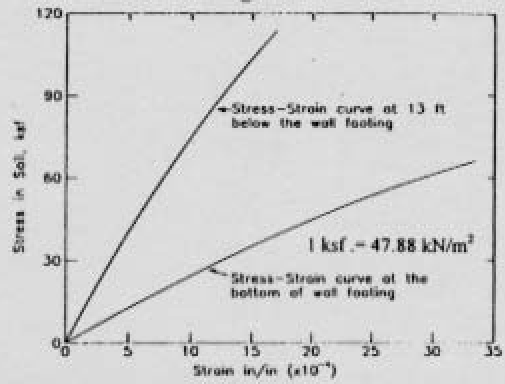


Variation of nodal strain in soil along the wall centre-line of 9 ft (2.74 m) high wall

Effect of Moment of Inertia of Retaining Wall Base and Footing

The results of the FE analysis shown in Figures 6 and 7 verifies that by neglecting the effect of moment of inertia of wall base and the footing, traditional methods do not introduce any significant error and no improvement is necessary to incorporate the effect of this factor.

Figure 4

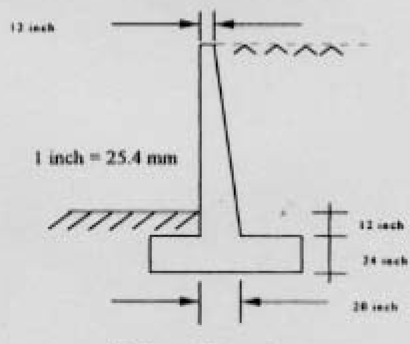


Stress-strain diagram at two different locations in soil below the wall

TABLE 1
RANGE OF PARAMETERS

Inertia at wall base (ft^4)	Inertia of wall footing (ft^4)	Slope (degree)	Unit weight (pcf)
0.0833	0.6667	0	100
0.1323	1.0587	5	110
0.1975	1.5803	10	120
0.2813	2.2500	15	-
0.3858	-	20	-

Figure 5

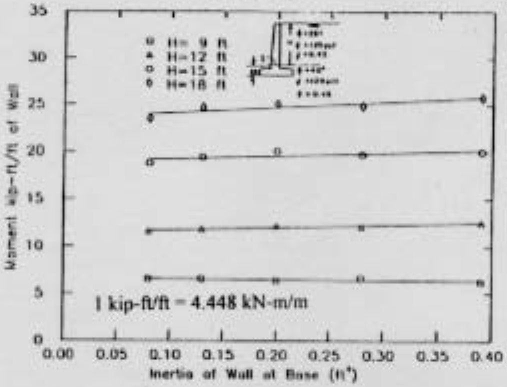


Basic problem set-up

Effect of Slope of Soil Surface

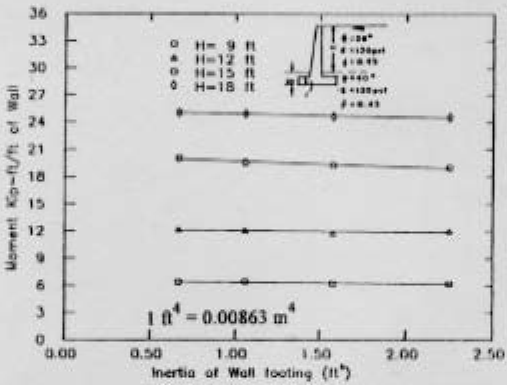
Figure 8 shows graphically the variation of moment at wall base with increasing slope of the backfill material. It appears that for a small increase in the slope of soil surface there occurs an appreciable increase in the horizontal force and the moment that is to be resisted by the wall. The performance of traditional design methods with respect to FE studies will be presented later in this paper.

Figure 6



Effect of inertia of wall at its base on moment to be resisted by it

Figure 7

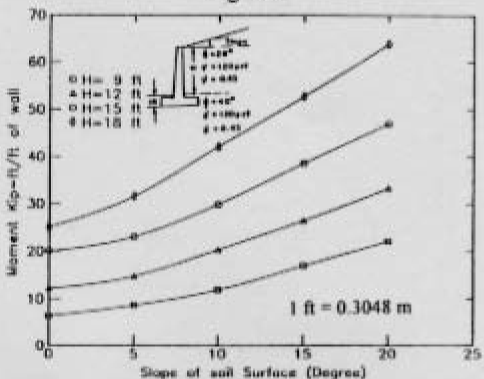


Effect of inertia of wall footing on moment to be resisted by the wall

Effect of Unit Weight of Backfill Material
Traditional methods, from their analytical formulation, show that lateral soil pressure force is directly proportional to the unit weight of backfill material. To verify this proportionality, analysis were conducted for retaining walls with various backfill materials. Results of the finite element analyses are graphically presented in Figure 9 which shows that the unit weight of backfill material is, indeed, a linear contributor to lateral soil pressure force, as postulated in the traditional ways of thinking.

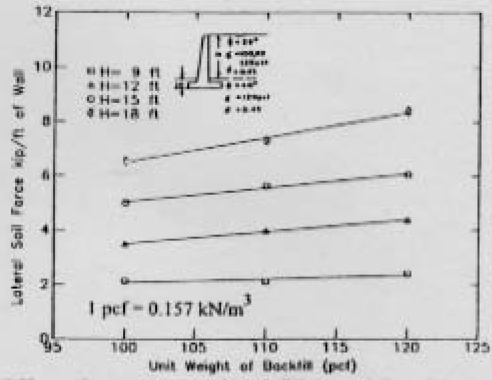
Effect of Line Load
The effect of line load on lateral soil force, with reference to a 9 ft (2.74m) high wall, is graphically presented in Figures 10 and 11. Figure 10 shows the total effect of self weight and line loading. At any stage of loading, the effect of line load can be obtained by deducting the initial ordinate from the ordinate corresponding to that loading. While Figure 10 shows that the magnitude of lateral force varies linearly with the magnitude of the line load, Figure 11 shows that lateral force decays with increasing distance of load from the wall.

Figure 8



Effect of slope of soil surface on moment to be resisted by the wall

Figure 9



Effect of unit weight of backfill material on lateral soil force

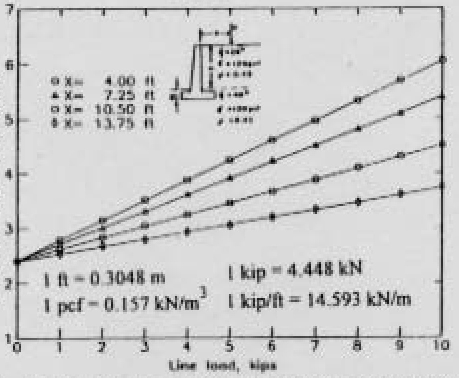
Effect of Distributed Load
The effect of distributed load on the lateral soil force, with reference to a 12 ft (3.66 m) high wall, is shown in Figure 12. From the figure it can be seen that the variation of moment and shear with respect to load is linear.

COMPARATIVE STUDY

For Self weight of Backfill Material
Figure 13 presents the graphical representation of obtained results obtained from FE analysis by

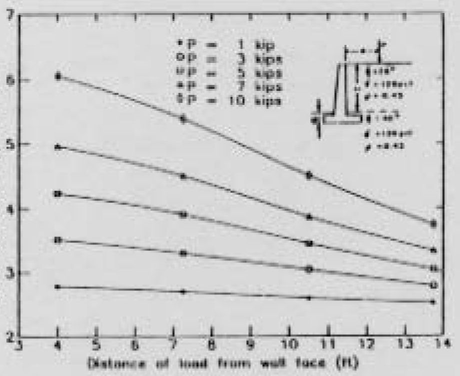
varying the slope of backfill material and then comparing them with traditional methods. It can be seen that although initially the FE results fall below the points obtained from other methods, as the slope of the backfill material increases the reverse seems to be the true.

Figure 10



Effect of line load on active earth pressure force for a wall of 9 ft (2.74 m) height

Figure 11

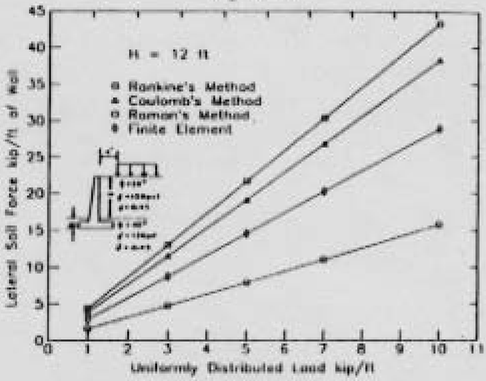


Effect of distance of load on active earth pressure force for a wall of 9 ft (2.74 m) height

For Line Load

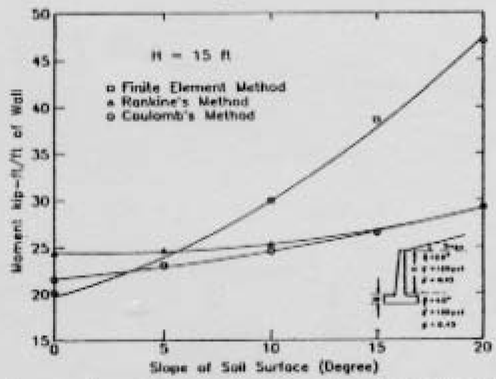
To compare the results of numerical results with results given by Boussinesq equation or Trial Wedge method, line load of 10 kip per feet (146 kN/m) width of wall was selected. Results are graphically presented in Figure 14. Boussinesq equation or trial wedge method shows that the magnitude of forces acting on the wall decreases as the distance of the line load increase from the wall. Magnitude of the active earth pressure force obtained by numerical analysis seems to fall between those obtained by trial wedge method and the Boussinesq equation. Studies by Ahmed (1993) has also shown that for same line load, such effects are greater for smaller walls, the other two methods show the opposite.

Figure 12



Comparison of active earth pressure force for uniformity distributed load

Figure 13



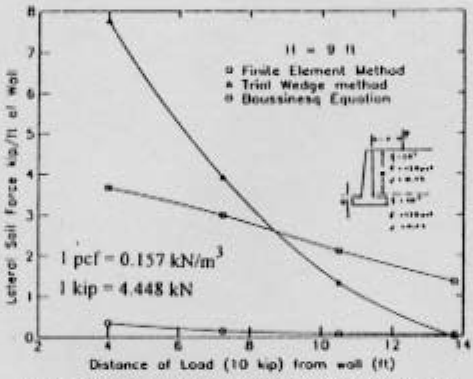
Comparison of moment with varying slope of soil surface

For Uniformly Distributed Load

Results of numerical analysis are graphically presented in Figures 15 and 16. It has been observed that for walls with relatively smaller heights, Ramon's method gives smaller values of active earth forces than the Coulomb, Rankine or FE method. But for relatively large walls, the FE analysis gives least values when compared to other methods. The similarity between all the cases is that the magnitude of the active earth pressure forces increase with the magnitude of the applied load and the variation is almost linear.

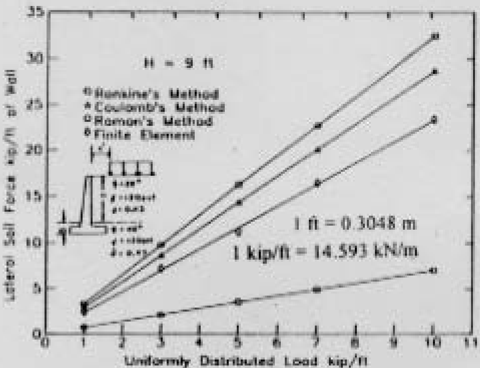
Rankine and Coulomb's method assumes a constant distribution of lateral pressure for the uniformly distributed load. So, the resultant active earth pressure force is located at the mid height of the wall. Ramon gave a complicated expression for the location of the resultant force. Numerical findings indicate that location of resultant force is independent of the magnitude of applied load.

Figure 14



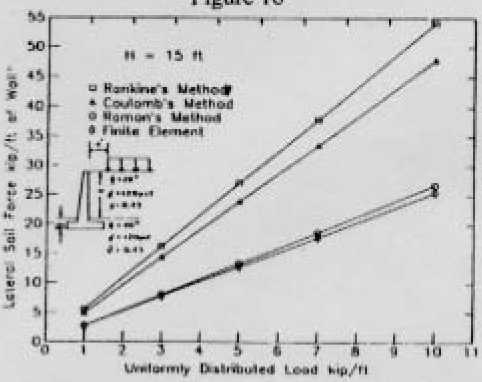
Comparison of active earth pressure force by varying position of line load

Figure 15



Comparison of active earth pressure force for uniformity distributed load (H = 9 ft (2.74 m))

Figure 16



Comparison of active earth pressure force for uniformity distributed load (H = 15 ft (4.57 m))

CONCLUSIONS

The traditional methods do not introduce any significant error by neglecting the effect of moment of inertia of wall and footing, and no improvement of formula is necessary. Slope of soil surface is an important factor to calculate thrust on the wall. Unit weight of backfill material is, indeed, a linear contributor to lateral soil pressure force. Magnitude of moment to be resisted by the wall at its base as given by finite element analysis is greater for walls having smaller heights, compared to that given by Rankine's or Coulomb's method. However, Rankine's method gives larger value of moment after a certain wall height, when the backfill material is horizontal, as compared to numerical analysis results. But finite element results show that the magnitude of moment increases sharply with increasing slope than Rankine's or Coulomb's method. Magnitude of moment to be resisted by the wall at its base for line loading has been found to be proportional to the magnitude of applied load, which is consistent with Boussinesq equation. Rankine's, Coulomb's or Ramon's method show that for the same uniformly distributed load, greater active earth pressure force and moment are obtained for larger walls. Interaction analysis via finite element method indicates that there is a critical wall height for a given load for which the effect of uniformly distributed load is maximum.

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