Earth Reinforcement, Ochiai, Yasufuku & Omine (eds) © 1996 Balkema, Rotterdam. ISBN 9054108339

Tensile force distribution along the reinforcement for reinforced soil foundations

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ABSTRACT: In a reinforced soil bed system reinforcement layer is usually placed with or without end anchorage. Since soil is weak in tension reinforcement develop tension under the applied load or the displacement of the footing. This tensile force is distributed along the length of the reinforcement subjected to the end condition. The reinforccement tension helps in distributing the load over a wider area, and becomes more effective at large induced settlements. As a result, vertical componenent of tensile force generated becomes effective in reducing applied load. However, very few studies to quantify the tensile force along the reinforcement have been reported in the literature. In this paper an attempt has been made to obtain the true nature of tensile force distribution along the reinforcement. For a reinforced soil bed below a strip footing this paper brings out induced tensile force distribution along the reinforcement at different load levels and for different types of reinforcements.

1 INTRODUCTION

In reinforced foundation system reinforcement layers are generally placed below the footing with or without anchorage. Reinforcement develop tension under applied load or displacement of the footing. This tensile force is developed due to the frictional interface interaction between the soil and reinforcement and is distributed along the length of reinforcement. It is also an well established fact that degree of improvement in load carrying capacity of the soil is function of type of soil, type of the reinforcement and properties of the reinforcement. The diversity of the type of reinforcement utilised (such as inextensible or extensible, continuous or grid) have made it necessary to perform numerous investigations to study the various interaction mechanisms and behaviour. Very few studies to quantify the tensile force along the length of the reinforcement have been reported in literature.

This paper is an attempt to model reinforced soil bed system and quantify the tensile force distribution along the reinforcement using nonlinear finite element method.

2 SOIL AND REINFORCEMENT PROPERTIES

A nonlinear confining stress dependent, stress-strain behaviour model is used for the soil elements. A detailed description of the model can be had from Duncan and Chang (1970). The reinforcement or inclusion is modelled using two dimensional beam elements. The soil used in this investigation is uniform sand, which is same as the one used by the SINGH (1988), for carrying out the model plate load tests on reinforced soil beds. Required parameters such as K , n, K_b , m , R_f , c and ϕ of the soil have been arrived at using the triaxial test results carried out at three different confining pressures. Table 1 gives the properties and parameters of soil used in the analysis and for validation. The input properties for the reinforcement used in the analysis are given in the Table 2.

Table 1. Soil properties.

Type of the soil	sand
Unit weight, γ	1.73 gm/cc
Cohesion, C	0
Angle of friction, ϕ	41°
Constant, K	540
Constant, K_b	489
Exponent, n	0.34
Exponent, m	0
Failure Ratio, R_f	0.67

Table 2. Reinforcement properties.

Reinforcement	Type A	Type B	Type C
Thickness, cm	0.05	0.18	0.05
Length, (cm)	45.6	45.6	45.6
area, (cm^2/cm)	0.05	0.18	0.054
Moment of Inertia, I (cm^4/cm)	$1.31X10^{-5}$	$2.811X10^{-4}$	$1.31X10^{-5}$
Yield Stress, (kg/cm^2)	1,260	592	260
Youngs modulus kg/cm^2)	$1.5 X 10^{6}$	4900	490

3 FINITE ELEMENT ANALYSIS

Reinforced soil bed, is represented by a footing on a cohesionless granular material which is strengthened by stiffer inclusions, is presented in the Fig.1. The finite element mesh used for the analysis is as shown in the Fig.2. The soil is represented by a series quadrilateral elements.

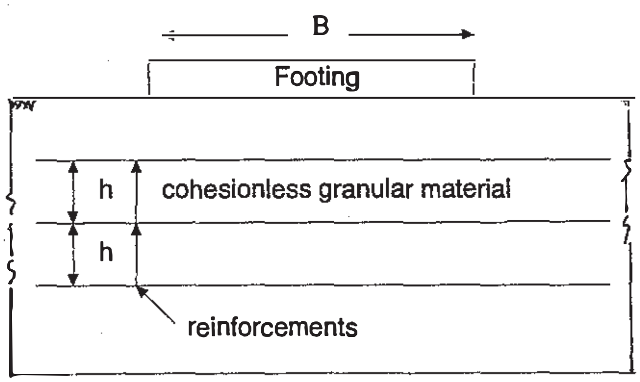

Fig.1 Footing on a reinforced soil bed

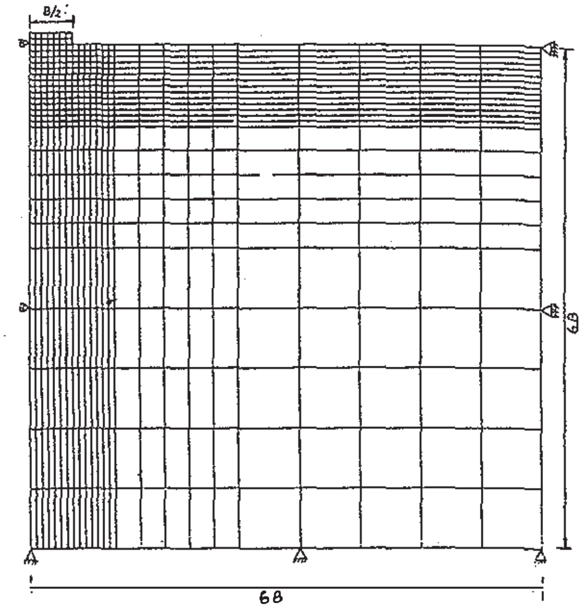

Fig.2 Finite element mesh used in analysis

The footing is modelled as shown in the Fig.2. Footing elements are assigned with a very high modulus values to represent a rigid footing. The finite element mesh used is of dimensions (6B x 6B), where B is the width of the footing. The width of the footing considered in the analysis is 15.24 cm.

Validation of the model: Numerical simulations have been carried out for a strip footing of 15.24 cm resting on both unreinforced and reinforced sand beds and are compared with exactly similar experiments (on a footing of dimension 15.24 x 91.4 cm) carried out by Singh (1988), in our laboratory. The comparison of the results between the experimental results and the numerical results is illustrated in Fig.3.

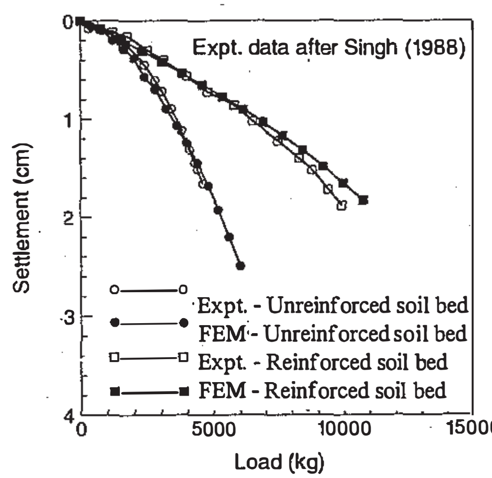

Fig.3 Comparison of experimental and FEM results

The detailed information of the experimental setup and the data of load-settlement behaviour can be obtained from Singh (1988). It can be seen that the load settlement curves form the finite element analysis and the experiments are in good agreement upto about 1.5 cm footing settlement.

4 RESULTS AND DISCUSSIONS

Finite element analysis have been carried out for reinforced soil beds with different types of reinforcement such as type A, B and C. In all these simulations the type of soil, length of reinforcement, depth of the reinforcement, load increments, and width of the footing are taken identical. The loading is applied sequentially in increments of 0.36 kg/cm^2 in all the three cases up to a maximum of 3.6 kg/cm^2. The presented results are for reinforced soil bed consisting of single layer reinforcement at depth of 40mm from the footing. The tensile force is evaluated from the axial force on the nodes of the interconnected beam element. Figs. 4, 5, and 6 show the distribution of axial tensile force along the reinforcement length at different loading conditions for different reinforcement types. In Fig.4, tensile force distribution along the reinforcement length for the analysis using type A reinforcement. The tensile force distribution is nonlinear in nature. Axial tension in the reinforcement below the centre of the footing is maximum, and is seen to be varied from 0.25 Kg to 14.5 Kg for load increments between 0.36 to 3.6 kg/cm^2 respectively. The magnitude of the tensile force developed in the reinforcement increases with the increase in load on the foundation. The magnitude of tensile force in reinforcement decreases with increase in horizontal distance of the reinforcement from the centre of the footing. At the end of the reinforcement (X/B = 1.5), tensile force is almost negligible. Similar trend of results have also been reported by earlier researchers for inextensible reinforcements based on their simple analytical methods (Huang and Tatsuoka, 1988, and Balakrishna, 1992). In Fig. 5, the tensile force distribution is presented along the length of the reinforcement using type B material. It can be seen from the Fig.5 that maximum tensile force has occurred in the region between the footing centre and footing edge unlike in analysis of type A reinforcement. The maximum tensile force developed is around 5 Kg for 3.6 kg/cm^2 and minimum tensile force observed is 0.15 Kg for 0.36 kg/cm^2 applied load on the footing. In this case also,

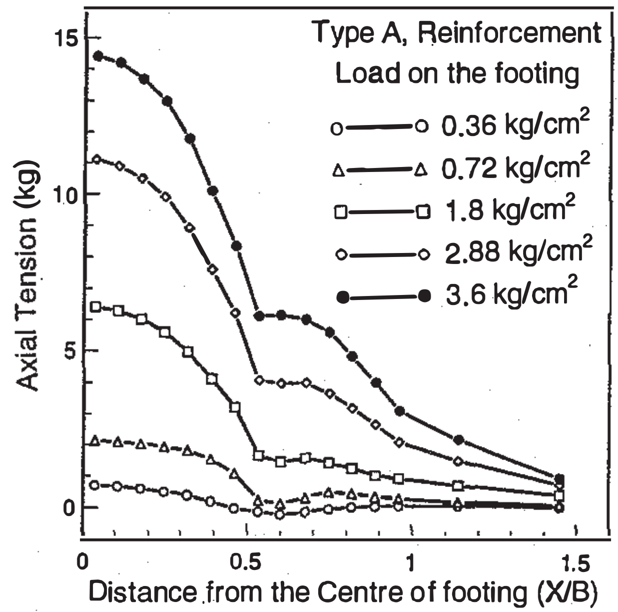

Fig.4 Tensile force for type A reinforcement

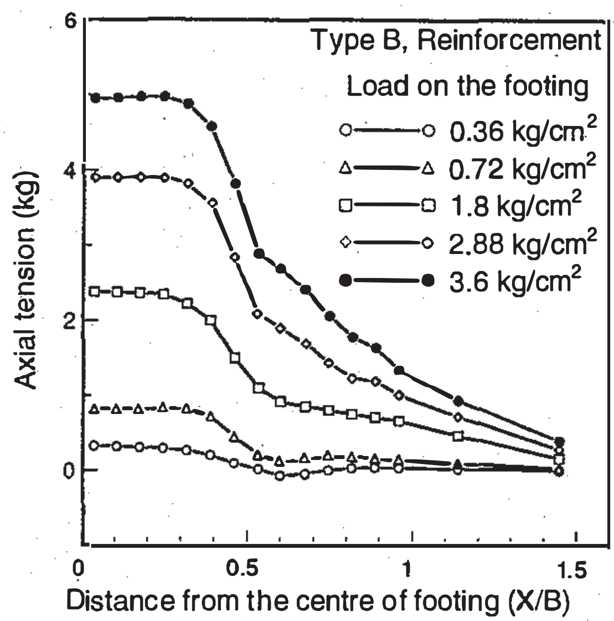

Fig.5 Tensile force for type B reinforcement

as the X/B increases tensile force decreases beyond the edge of the footing.

In Fig. 6, the variation of tensile force using the type C reinforcement under different footing loads. In this case It is important to note that maximum tensile force has been developed at the edge of the footing. Similar observation was recorded by Burd and Brocklehrust (1990) while investigating reinforced unpaved road under single monotonic load. For type C material, the magnitude of the tensile force developed is 0.05 kg to 1.1 kg for

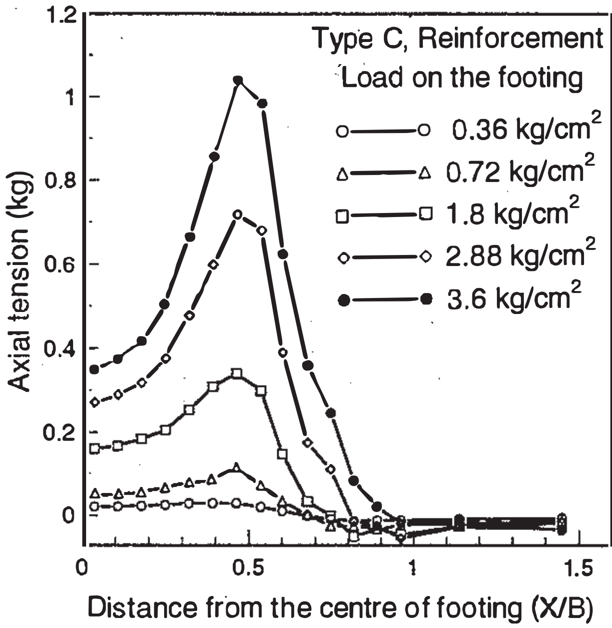

Fig.6 Tensile force for type C reinforcement

loading increments between 0.36 to 3.6 kg/cm^2 respectively. As the value of X/B increases beyond 0.5 (edge of the footing) tensile force decreases. For inextensible or high stiffness of the reinforcement such as type A, maximum tensile force develop at the centre of the footing.

As the stiffness of the reinforcement decreases the point of maximum tensile stress development shifts towards the edge of the footing. The reinforcement becomes more effective at higher load levels as the tension developed in the reinforcement is higher for higher load in all the three cases.

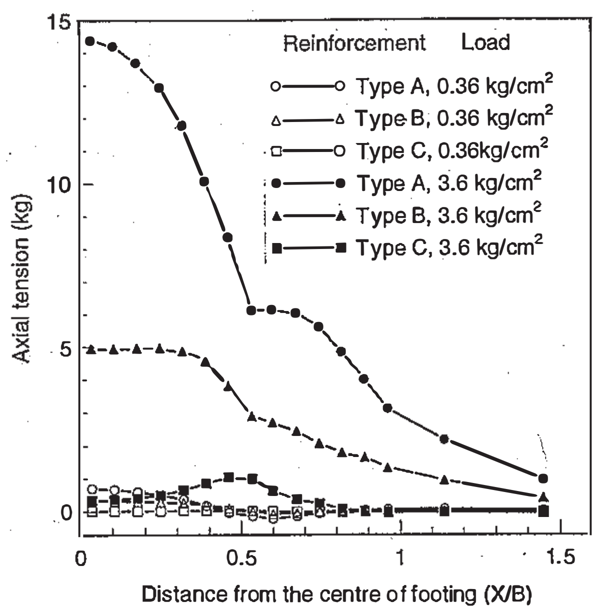

Fig.7 Comparison of tensile force distribution for type A, B and C reinforcements

Fig. 7 presents the comparison of developed tensile force and its distribution along the reinforcement length for all the three type of reinforcements A, B and C. The trend of shifting of occurrence of point of maximum tensile force development along the reinforcement can be easily seen in this figure.

5 CONCLUSIONS

The tensile force developed along the length of the reinforcement has been quantified using a suitable nonlinear hyperbolic soil- reinforcement interaction model, and following conclusions are drawn:

1. The tensile force distribution along the length of reinforcement is nonlinear. The stiffness of the reinforcement plays a vital role in determining the magnitude of the developed tensile force in the reinforcement. Higher the reinforcement stiffness, higher is the tensile force.
2. The location of point of the maximum tensile force depend on the stiffness of the reinforcement.
3. At lower load levels, the type of the reinforcement does not influence the tensile force in reinforcement.

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