Fundamental Study on the Safety of a Reinforced Embankment

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Fundamental Study on the Safety of a Reinforced Embankment

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Abstract

This report shows analytically displacemental characteristics of a reinforced embankment with a few steel strips or nets by using F.E.M. considering elastoplastic characteristics of materials.

The safety of a reinforced embankment is effected by materials which are soils and reinforcements and by their interactions.

In this report, the effects of introducing reinforcements are investigated on displacements and stress of embankments which possess a few strips or nets at various depth in them.

From calculated results, some important parameters effecting to the safety of a reinforced embankment are investigated and possible patterns of failure in the embankment are shown schematically.

Introduction

A reinforced embankment is composed of various soils and other materials such as metal or resin. These materials' interaction make the slope of an embankment steeper than in the case of normal embankments composed of only soils. These materials are generally called "*reinforcements*".

These mechanical characteristics are considered that frictional forces on boundary faces between soils and reinforcements make soils stronger and so, shearing force in soils is weakened as its direction is changed toward un-clockwise. As the results, horizontal displacements are constrained.

However, soils have various characteristics and also reinforcements take various nature according to the controlling of their producing.

In this paper, the effects to introducing reinforcements into soils are investigated analytically from displacements and stress in embankments. Where, it is assumed that reinforcements are such as strip types and soils have constant physical coefficients.

Consequently, qualitative characteristics of reinforced embankments are discussed in this paper. And important design parameters of reinforced embankments are found and their relationships are considered.

Analytical Model and Analytical Method

When reinforced embankments are constructed, soils and reinforcements are filled up as layered. And so, in analysis, these mechanics are introduced. Here, the reinforced embankment is divided by 10 layers and is analysed by using filling up analysis. After the last layer is filled up, loads are loaded incrementally at the top of embankment as line loads and yielding elements in a model are researched. An analytical model is shown in Fig. 1 and boundary conditions are given on the diagram.

Here, the angle of the slope is 45° and bar elements and joint elements are used to express some characteristics of boundary faces between soils and reinforcements.

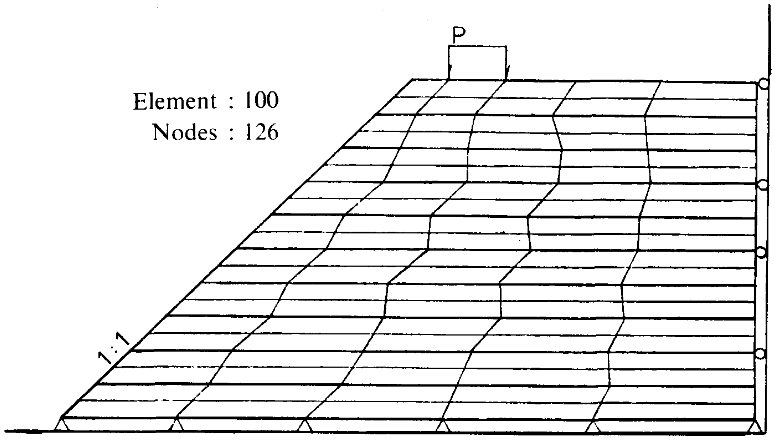

Fig. 1. F.E.M. Model

Fig. 2 shows the relationships of stress-strain of soils. Elements of soils are analysed by elastoplastic method and reinforcements' elements are analysed by non-linear method and are assumed to failure at the maximum displacement.

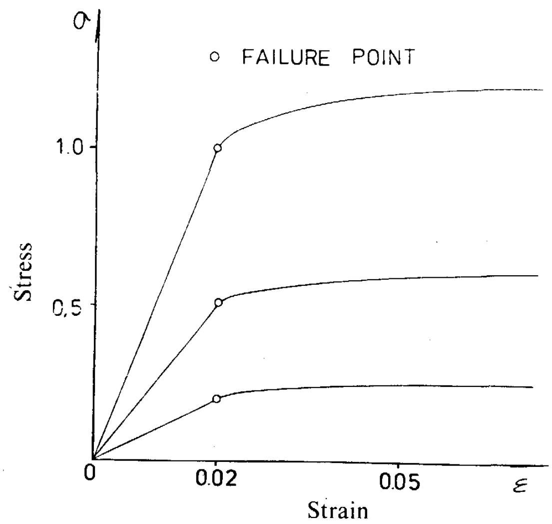

Fig. 2. Stress-strain curve

Table 1 shows the physical constants of materials.

Table 1. Physical Coefficients

Soil Element	E_{s1} = 50.0 kgf/cm²	ν = 0.3
Reinforcement	E_r = 7.3*10⁵ kgf/cm²	ν = 0.3
Boundary Element	E_{s2} = 25.0 kgf/cm²	ν = 0.3

Results and Consideration

In this paper, firstly, the effects of introducing of reinforcements into embankments are investigated analytically, the characteristics of deformations and distributions of stress of reinforced embankments are forcused especially. And secondarily some important parameters of reinforced embankments are found and mutual cooperations are considered.

(1) Horizontal and Vertical displacements

Fig. 3 shows the displacements of a general type of embankment with no reinforcements, having homogenious materials of $E_s = 50.0$ kgf/cm^2 and $\nu = 0.3$. In this diagram, NO. indicates the state of elastic deformation and N_i indicates the state that i elements have yielded. From this figure, it is found that the maximum horizontal displacement occures at the middle surface of the slope and become larger as yielding elements are increasing and that vertical displacements become larger beneath the loading points. This tendency is seen in real embankments as a slop failure.

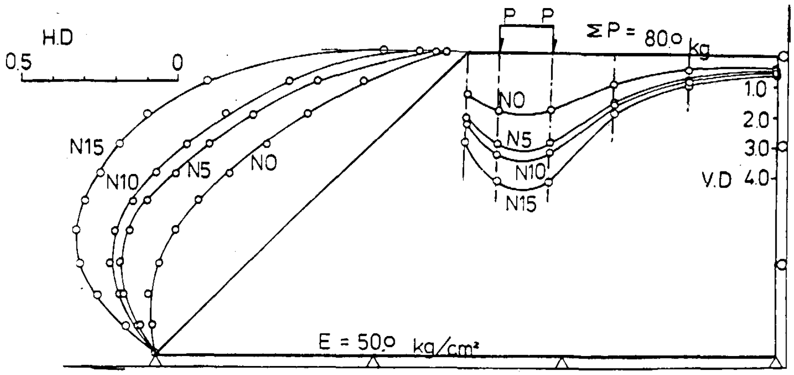

Fig. 3. Displacement of an embankment without reinforcements

Fig. 4 shows the displacements of the reinforced embankment with ten layers of reinforcements. In comparison with the previous case, horizontal displacements are constrained by half of the former in the elastic deformation resion. And also, in the elastoplastic zones, the effect of constraining horizontal deformations are larger as the load is increasing. But on vertical displacements, the effects of reinforcing are not recognized.

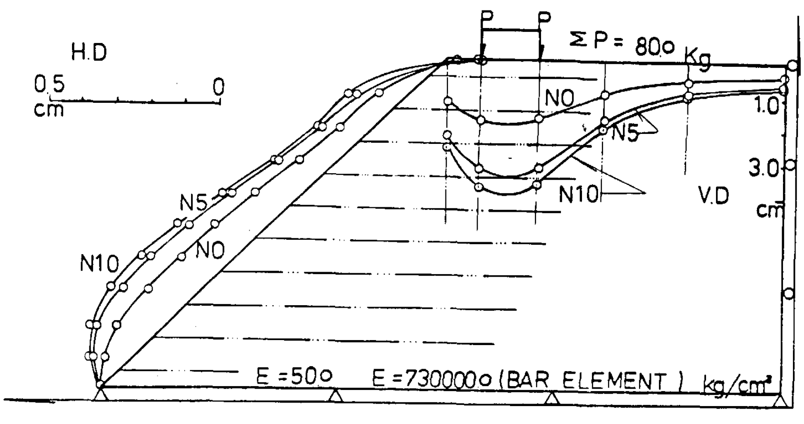

Fig. 4. Displacement of reinforced embankment with 10 reinforcements

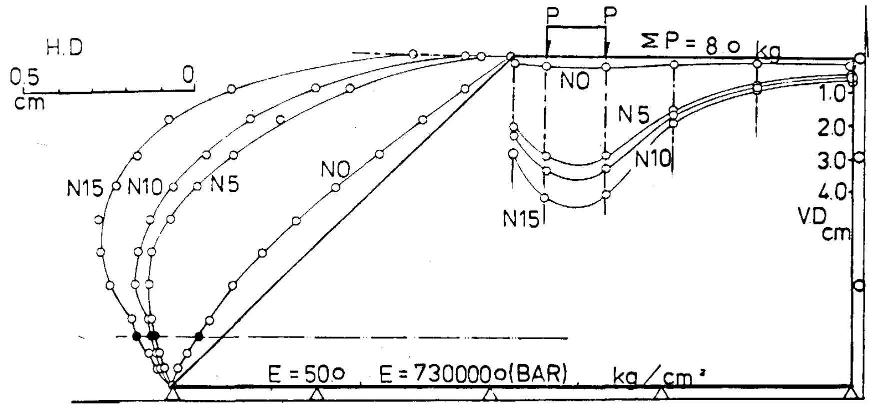

Fig. 5. Displacement of reinforced embankment with one reinforcement for 1st case

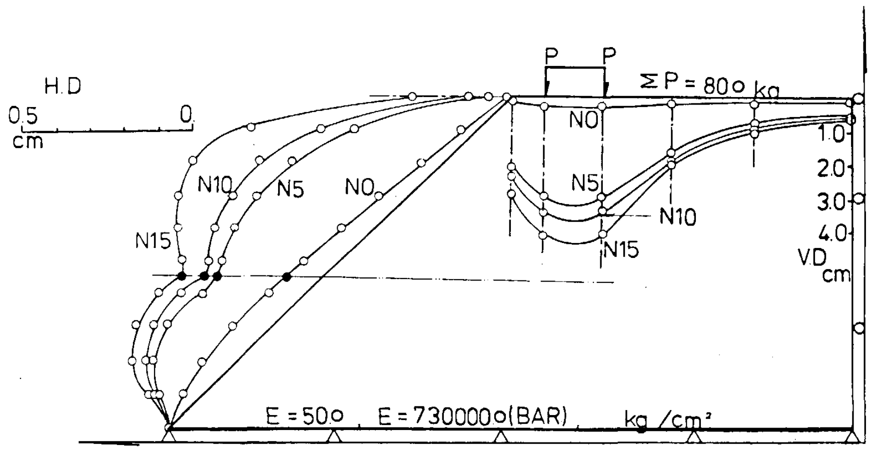

Fig. 6. Displacements of reinforced embankment with one reinforcement for 2nd case

From these results, it can be seen that reinforcements may have possibility to restrain horizontal displacements and to improve the safety of embankments. As these results show a general tendency of deformations for reinforced embankments, more details of each reinforcement are shown as below.

Fig. 5 – Fig. 8 show deformations of another four cases taking one reinforcement at various elevations. From these results, it can be found that even though the same reinforcement is used, there are some difference of deformations according to the spacing. That is, near at the top or the bottom of an embankment, the effects of reinforcements are not so much. And even at the middle, it may be possible for another type of failure to happen by spacing methods.

Therefore the spacing method of reinforcements is one of important parameters to the design of a reinforced embankment.

Nextly, other examples which a shorter reinforcement is spaced are shown in Fig. 9 and Fig. 10. It can be seen that the effects of a reinforcement does not appear when a very short reinforcement is used. On the other way, when the length of a reinforcement is too large, it may be not economical. Therefore, the length of a reinforcement is also one of the design parameters.

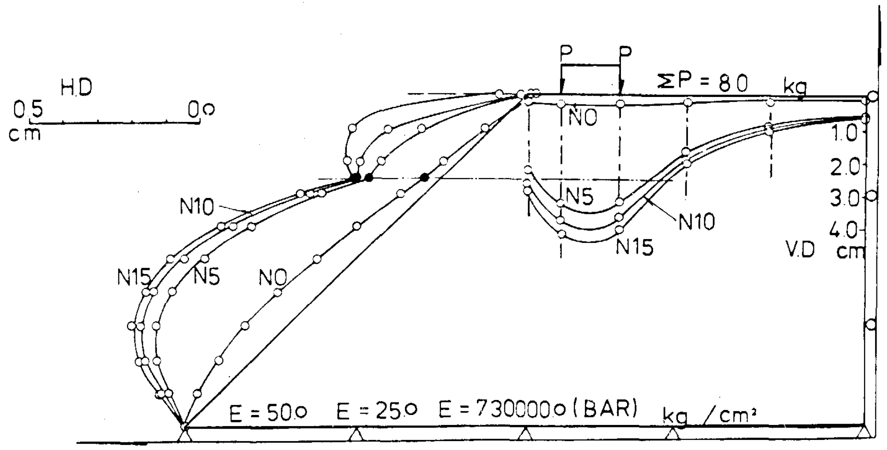

Fig. 7. Displacement of reinforced embankment with one reinforcement for 3rd case

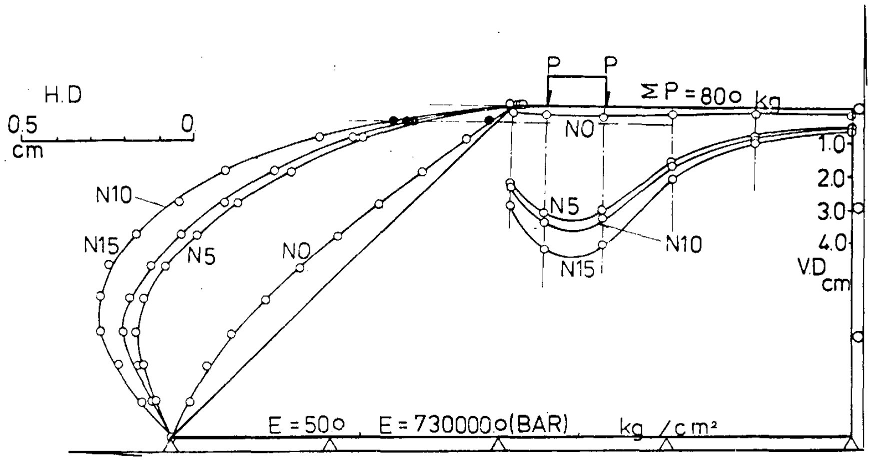

Fig. 8. Displacements of reinforced embankment with one reinforcement for 4th case

These above results are of the cases which the nature of sliding on boundary faces between soils and reinforcements are not considered. But in the reinforced embankments, sliding may happen on the boundary faces. And so, to simulate such a sliding, another elements which have a different nature from soils are introduced in analysis and the results are shown in Fig. 11 and Fig. 12. Where their elements was assumed to have the half value of elastic modulus of soils. From these results, the befavior of sliding can be seen at the faces of reinforcements. That is, horizontal displacements upper parts of reinforcements are larger than lower parts of them.

Similarly, the cases which joints elements are introduced at boundary parts of reinforcements are shown in Fig. 13 and Fig. 14.

In these cases, the same behavior can be seen. But here, the vertical and horizontal stiffnesses to the sliding must be well investigated in analysing.

Conditions to such sliding are related with the characteristics of shearing forces at boundary faces and pulling-out forces of reinforcements. These two parameters are also important.

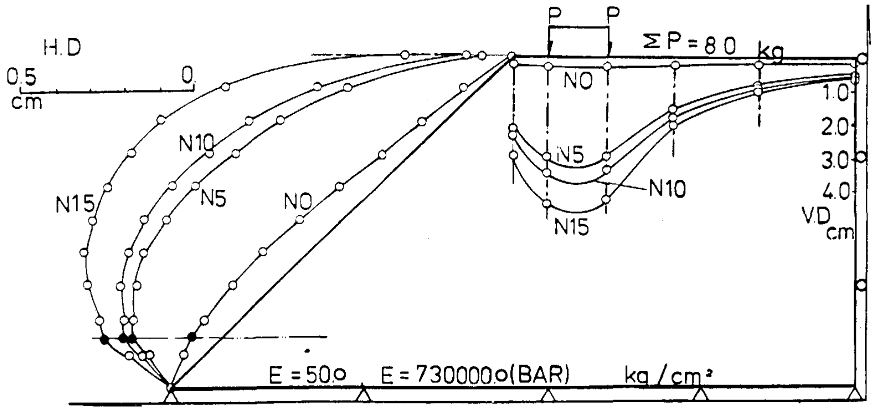

Fig. 9. Displacements of reinforced embankment with one short reinforcement

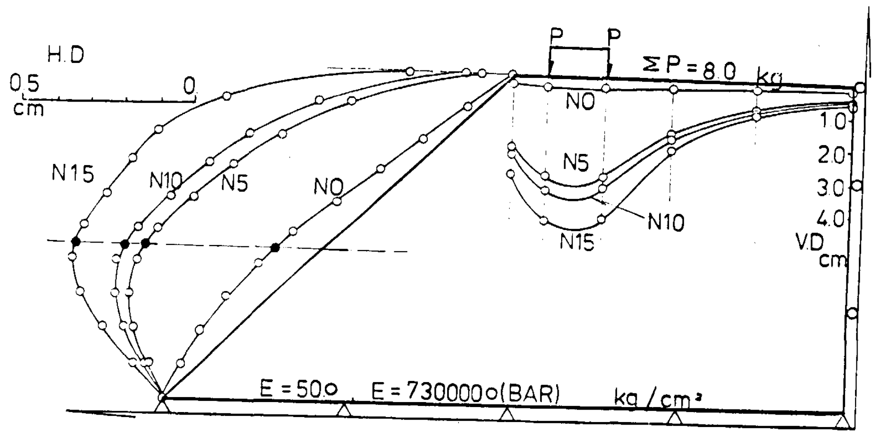

Fig. 10. Displacements of reinforced embankment with one short reinforcement

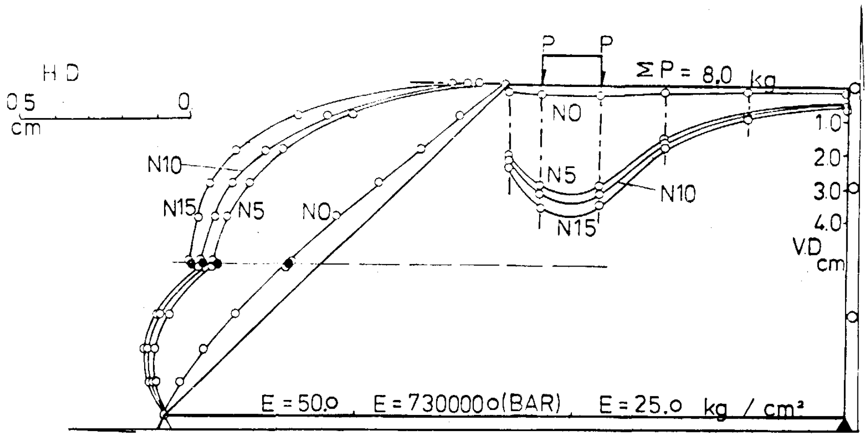

Fig. 11. Displacements of reinforced embankment in the case of using different element at near one bar element

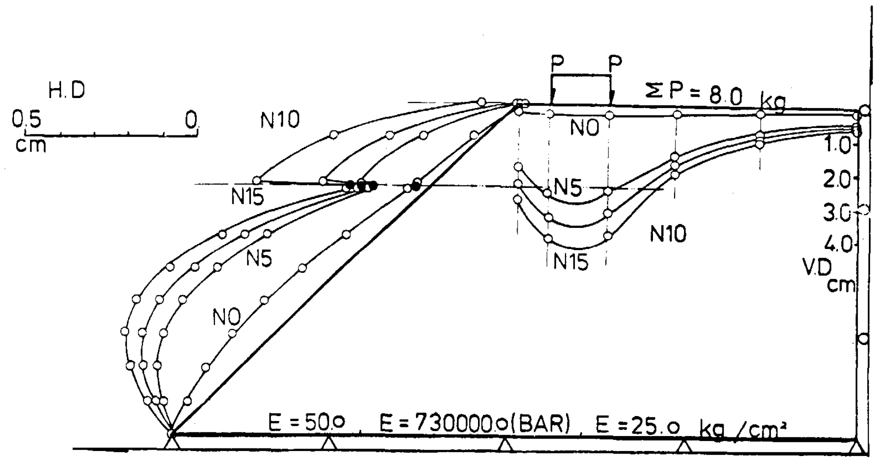

Fig. 12. Displacements of reinforced embankment in the case of using different elements at near one bar element

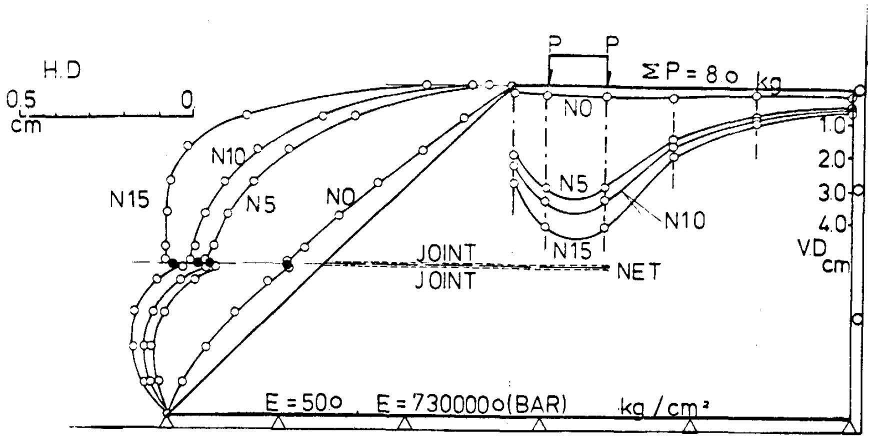

Fig. 13. Displacement of reinforced embankment in the case of using joint elements

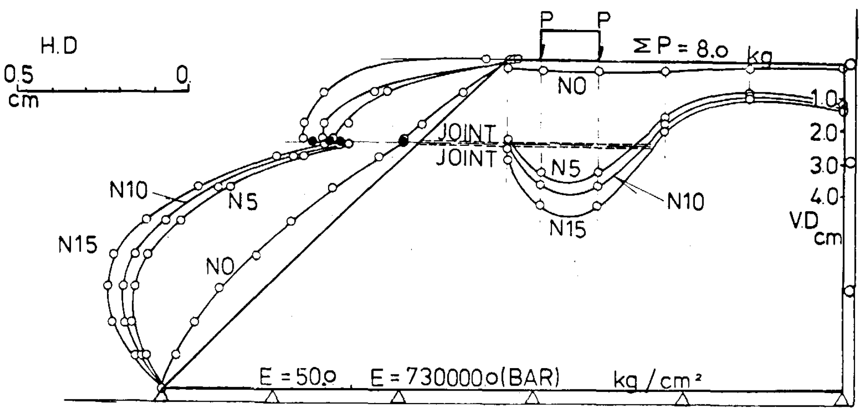

Fig. 14. Displacements of reinforced embankment in the case of using joint elements

(2) Distributions of Stress in Reinforced Embankments

In this section, the distributions of stress in embankments which contain same three reinforcements at a equal distance apart are described. Where, reinforcements are expressed as "bar element" and boundary conditions of embankment's base are free to the horizontal direction. And the effects of increasing loading at the top of embankments are mainly discussed.

Fig. 15 shows the distribution of principal stress (σ_1) at the state that 10 elements have yielded in the embankment. From this figure, the stress concentration happens in upper layer, but below it, similar states are seen in inner parts of the embankment except at near the slope, and at near the slope, tensile stress appeares but it is not so large.

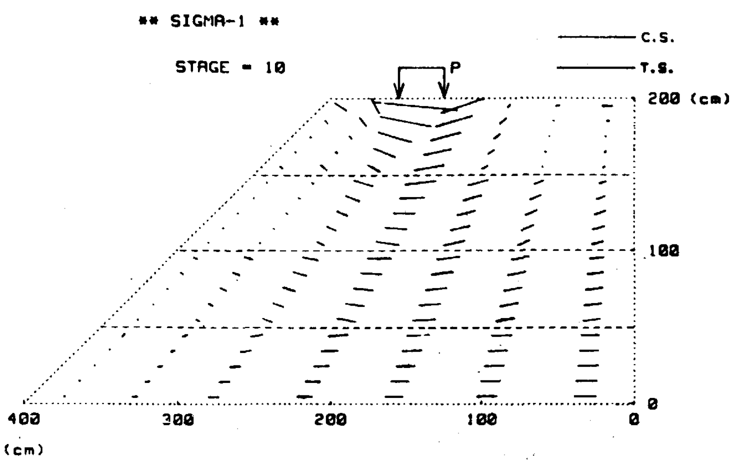

Fig. 15. The distribution of pricipal stress σ_1 at the stage N10

Fig. 16 shows, similarly as in Fig. 15, the distribution of shearing stress (τ_1). It is considered from this figure that the larger stress are produced in the top layer under loading points and the larger compornents along a reinforcement are seen, which may cut or make sliding soils on it. But except these parts, the value of shearing stress are smaller as in lower parts.

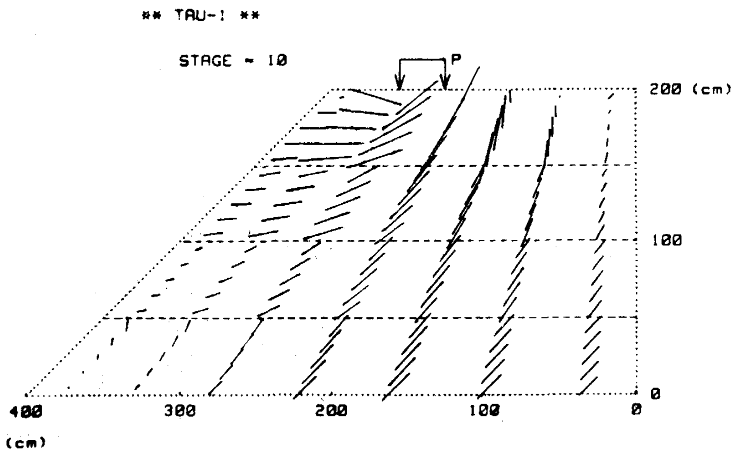

Fig. 16. The distribution of shearing stress τ_1 at the stage of N10

Fig. 17 shows the distributions of the stress (σ_X) at above and beneath each reinforcement. It is found that the difference of stress values along each reinforcement exists. It is related with the resistance in pulling reinforcements from soils and the physical states of reinforcements' faces. These are also the important design parameters to the reinforced embankments.

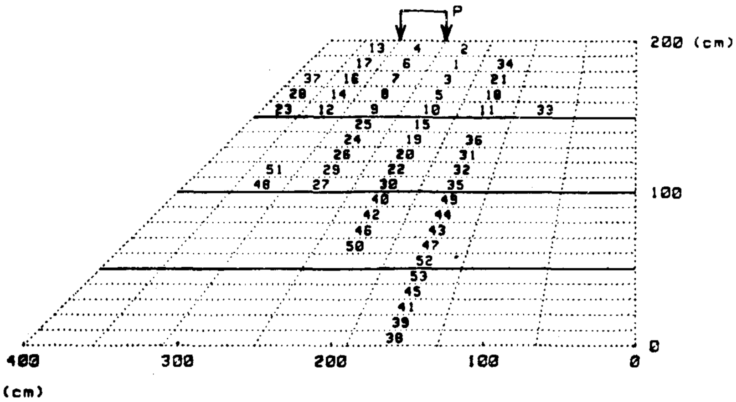

Fig. 17. The distribution of stress ν_X at near reinforcements

Though is lacks the strictness, Fig. 18 shows the progressive resion of yielding elements, where numbers in the figure mean a yielding order. It is found from this figure that an initial yielding region concentrates to the highest layer. Although it depends a type of a embankment, it is considered, to comparison with other type which have more little layers, that the introducing of reinforcements can make the safety of lower layers higher.

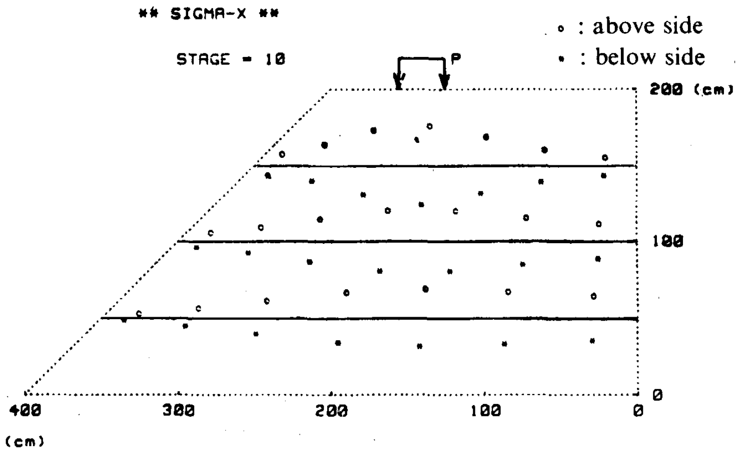

Fig. 18. Order of yielding elements

Accordingly, in the case of simply reinforced embankment as previously shown, it is possible for embankments to failure at boundary parts of upper layers and at the parts of loading and so, it is needed to compact those parts carefully at the construction to make the bearing capacity of each layer higher.

From the results as previously described, following patterns of failures possible to happen in reinforced embankments can be considered as shown in Fig. 19.

In this figure, ① means "*sliding failure*" on the faces of reinforcements, ② means "*shearing cut*" of them, ③ means "*pulling out failure*" due to lacks of pulling resistance of them, and ④, ⑤ and ⑥ correspond to the combinations of ①, ② and ③.

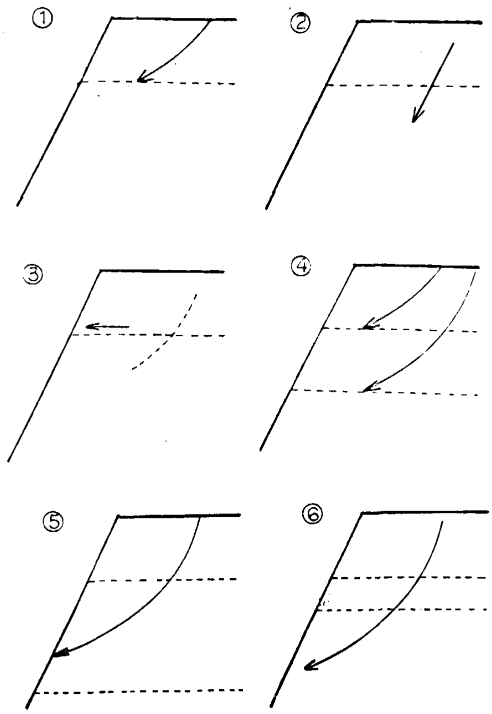

Fig. 19. Failure patterns for reinforced embankments

Conclusions

From above results, it can be assumed that the relationship among parameters which are important to deformations of reinforced embankments is as follows;

$$F_d = f(s, L, \tau, n)$$

where, F_d: the Horizontal Displacement of a Reinforced Embankment
s: the Spacing
L: the Length of a Reinforcement
τ: the Frictional Resistance at Boundary Faces between Reinforcement and Soils
n: the Number of Reinforcements

These parameters are not independent to others and will act to the others. In brief, characteristics are as follows;

1) On "s", if n = 1, the horizontal displacement F_d will take minimum values when a reinforcement is introduced at the middle height of a embankment. But if n increases, F_d will be smaller and smaller. And n will have a optimum value.
2) On "L", when s is limited, the larger L is, the smaller F_d become. But it is considered that the effect of constraining horizontal displacements will have the limits.

3) On "τ", it is generally said that τ has the maximum value on a reinforcement along its axis, and at the point of which have the value, active and passive zone in soil are separated. But the boundary point is related with the co-operation between soils and reinforcements. And also, the vertical directional stress of the faces of reinforcements are effected by "s" or "τ".

When "s" is constant, the relationship among these parameters is expressed as follows;

$$\tau = T_1 - T_2 \quad \cdots\cdots (1)$$

$$\tan \psi > \frac{\tau}{2\sigma b\, dl} \quad \cdots\cdots (2)$$

where, T_1, T_2: Tensile forces at right and left side of dl
σ: Vertical stress
b: the Length of a reinforcement
dl: a small distance in a reinforcement
ψ: the frictional coefficient in soil,

If equation (2) is true, sliding in soil may not appear.

Though some primary factors affecting to the safety of a reinforced embankment are ascertained as previously shown, it is wanted to develope better program considering various conditions of the safety of embankments.

Reference

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