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Reinforcement of soil slopes by electrochemical methods

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ABSTRACT: This paper deals with a theory supported by practice and results of a method of stabilizing potentially unstable slopes of clayey soils by electrochemical methods. This investigation has established that the reinforcement of the soil massif lying on the pre-existing slip surface of ancient buried river bed by electrochemical methods combined with electrosilication have been found to be effective. As a result of this methodology of reinforcement, the strength of the the soil massif has increased by 1.5 - 2 times from the initial values. A reduction of humidity was also observed in and around anode and cathode locations by 7% - 4% respectively. Calculation carried out on the stability analysis of the slope after the electrochemical reinforcement show an increase of the factor of safety of about 1.25.

1 INTRODUCTION

Electrokinetic and electroosmosis phenomena can be observed in the higher dispersed soils under the action of direct electrical current. Passage of water through the interconnected pores between the solid particles is initiated not only by the hydrostatic or hydrodynamic pressures, but also due to the action of various physical and physico-chemical gradients which can be classified according to Sergev(1983) as:

1. Gradient of the field caused by direct electric current (electro osmosis).
2. Gradient due to the concentration of dissolved electrolytes (capillary osmosis)
3. Temperature gradient (Thermo osmosis)

During the passage of water between soil particles, displacement of liquid takes place along the surface of the soils under the influence of the surface forces. In clay soils with the particles of high specific surface, the flow of water takes place with velocities exceeding several times the velocity of the ionized liquid cementing the loose soil particles. Simmultaneously the potential of the electric field created by the metallic electrodes (Fig.1) emits ions from the metallic surface. These cations easily bind with the molecules of soil particles which finally reinforce the soil. The main disadvantage of both electroosmosis and electrolysis processes is the emission of heat. (Reauter 1978).

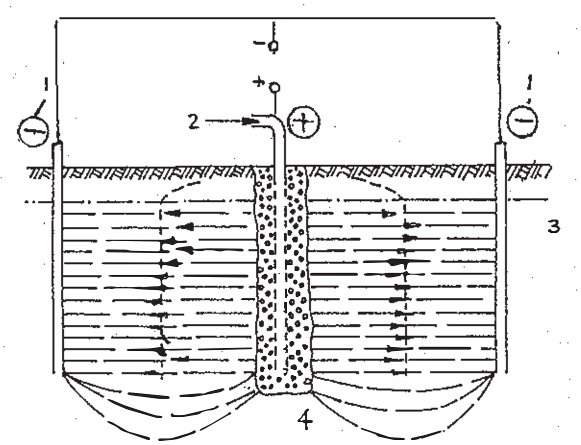

Fig.1 Schematic diagram of electrochemical reinforcement of soils. 1-Cathode, 2-Injection of solution 3-water table, 4-Anode filter, - - Direction of stabilization.

2 ELECTROCHEMICAL REINFORCEMENT

Artificial reinforcements of soils in the massif of potentially unstable slopes by electrochemical methods allow to control the over all stability of the slope. In order to improve the effectiveness of the electrochemical method of reinforcement of soils with different coefficients of permeability, the following methods were used in this work.

1. Reinforcement of soils with help of the emission of ions from the metallic surface of electrodes
2. Reinforcement with the help of solutions of electrolytes applied through the tube of the anode.
3. Reinforcement with the help of the quick hardening solutions applied on soils through the tube of anode or cathode.(liquid glass)

The investigation was carried out on the massifs of the potentially unstable slope of non uniform geological structures. In the area of slope failure, loamy clay of 7-10 M thickness was lying on Quartenary loams of 3-6 M thickness. It has also been found that the existance of buried ancient river beds under the slopes was mainly responsible for causing slope failures. In this pre-existing potential slip surface, a sudden increase of the humidity has been observed. The study area consisted of soils under the unfavourable geotechnical and hydrogeological conditions. The methodology developed for this study area is mainly dependent on the coefficient of permeability and the particle size distribution. It has been found that the soils of the slope consist of clay particles from 15-40% and the loamy clay particles of 22-70% with respective coefficient of permeability < 0.005 M/day and 0.5 to .005 M/day Under these conditions both electrochemical and electrosilication methodologies have been used to obtain maximum effectiveness.

3 MODEL STUDIES

In order to analyse the stress-strain state of the massif after the electrochemical reinforcement, model studies were carried out using model slopes prepared from optically sensitive materials (Illin 1985). Investigations have been carried out on 18 models of slopes corresponding to heights from 8 to 15 M. The main task of these investigations was to establish the most effective configuration of electrodes and also to establish the positioning of such configurations in the locations of the slope to obtain maximum effectiveness of the reinforcement. It has been found that the form of a hexagon with six anodes positioned at its corners with the cathode installed in centre was quite effective. Finally it has been found that the location of such a pattern is quite independent of the height of the slope. In these studies probable slip surfaces were drawn and the factor of safety (F) calculated. Fig.2 shows the most favourable positioning (in respect of the factor of safety) of electrodes for the slope of 10 M high. Fig.3 shows the changing of the factor of safety in respect of the distance of the configuration of electrodes positioning from the bottom of the slope of this model.

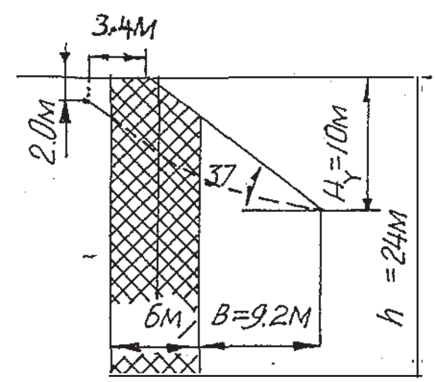

Fig.2 Positioning of electrodes for optimum effectiveness.

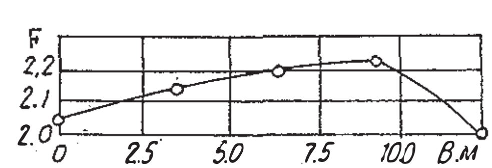

Fig.3 Plot of factor of safety (F) against the horizontal distance (B) from the toe of slope.

4 PROCESS OF REINFORCEMENT

During the reinforcement of the non operational benches of the open pit mine,a number of anode-cathode groups with the cathode positioned in the centre of the bore holes and the anodes in each of the corners of the hexagon were introduced as shown in Fig.4a. When the height of the slope exceeds 10 M,two rows of similar configuration were used (Fig.4b). Model studies conducted (Fig.2) for a slope with a height of 10 M showed that it is more effective to position electrodes partially under the inclined surface of the bench. This was necessary to reinforce the soil massif which is situated within the zone of active stresses.

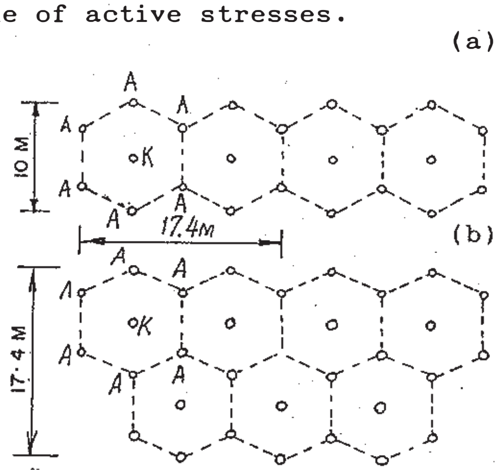

Fig.4 Plan of electrodes configuration in slope

The particular electrodes configuration and positioning adopted resulted in fully utilizing the electro potential energy and intensifying the electrochemical processes taking place within the space between the electrodes. Volume of soils thus reinforced was confined to the blocks of soil mass enclosed between the positive and negative electrodes (Perera 1983). The electrodes were made of metallic tubes provided with casing which pass through the full length of the bore holes. Diameters of anodes were between 42 - 50 mm and the cathode diameters ranged from 108 - 112 mm. Reinforcement of soils have been carried out in 67 blocks having an approximate volume of 80,000 cubic meters.

Because of the non uniform lithological profile and the existance of soils with different values of permeability, electrochemical and electrosilication methods of reinforcement of soils were also used. A 18% - 20% strength solution of calcium chloride and the liquid glass of density (1.05 to 1.10).10 Kg/M^3 were used for chemical injection. An electro potential of 320 volts was applied between the electrodes which maintained the potential gradient of 0.7 - 0.8 V/cm. This gradient of potential was maintained on each block of soil for a period of 360 hours.

As a result of this method of reinforcement the strength of the soil massif was observed to have increased by 50% to 75% of the initial value. A reduction of humidity was also observed in and around anode and cathode locations by 7%-4% respectively.Calculations carried out on the stability analysis of the potential slope after the electrochmical reinforcement of soils show an increase of the factor of safety by 25%. In addition, this methodology enabled construction of slopes with steeper angles. This helped to cut down the expenditure for additional stripping works. Further it was possible to increase the slope angle from 22° to 30° (Fig 5) and effected saving on expenditure by cutting down cost of extra stripping works by 51 cubic meters per meter length of slope (Perera 1986).

In order to evaluate the effect of the electrochemical reinforcement, experimental bore holes were drilled in the reinforced massif. This was carried out to cover areas between anodes and cathodes. Core samples were subjected to different laboratory tests for the determination of the strength properties. Calculation of the physico-mechanical characteristics of the massif before and after the reinforcement shows considerable increase of the strength properties of soils (Table 1).

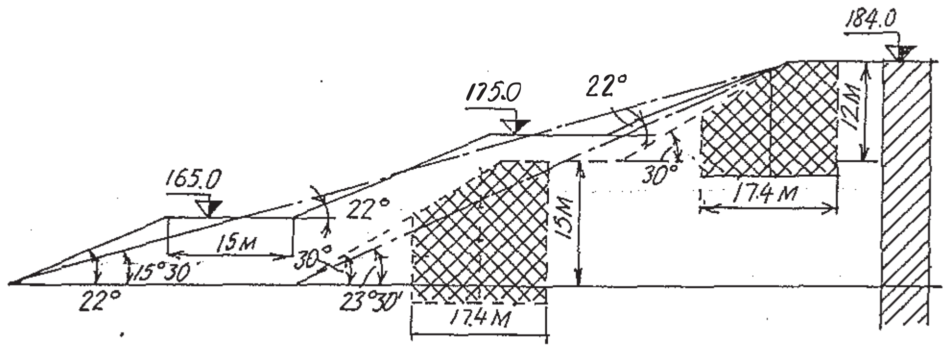

Fig.5 Diagram showing increase of slope angle obtained by electrochemical reinforcement of soil

Table 1.

Characteristics	Massif before Reinforcement	Massif After Reinforcement
Cohesion MPa	$3.0 \cdot 10^{-2}$	$6.0 \cdot 10^{-2}$
Angle of internal friction	21°	30°
Density Kg/M^3	$2.0 \cdot 10^{-3}$	$2.1 \cdot 10^{-3}$
Factor of safety	1.00	1.25
Humidity around A.	25%	18%
Humidity around C.	25%	21%

5 CONCLUSIONS

1.Basic theories of soil mechanics and physical chemistry are two important disciplines for the formulation and investigation of reinforcing potentially unstable slopes by electrochemical methods.

2.The concentration of tangential stresses is located in the depth range of 0.9 to 1.2 of the height of the slope as determined from model studies. The depth of the electrodes should therefore penetrate to a distance exceeding the height of the slope.

3. The reinforcement becomes more effective when the system of electrodes configurations is located in the regions covering the area where the soil slope intersects the horizontal top surface of the massif as shown in Fig.5.

4. Results obtained after electrochemical reinforcement was carried out, show that the soil strength increased by a range within 20% to 50% of the initial values. It was also observed that the humidity levels around the anode and cathode decreased by 7% and 4% respectively.

5. Electrochemical reinforcement methodology can be effectively used to control the stability of potentially unstable slopes situated on buried river beds where the presence of additional humidity can aggravate the stability criteria of the slip surfaces.

6.Steeper slopes can be formed using this particular methodology and extra expenditure for additional stripping works curtailed on of costs that would otherwise result in stripping, milder slopes in the open pit mining industry.

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