Ground Failure and Remedial Measures at a Block of Flats

I. Stanculescu
Civil Engineering Institute of Bucharest, Romania

A. Chirica
Civil Engineering Institute of Bucharest, Romania

Proceedings: Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, Paper No. 1.45

Ground Failure and Remedial Measures at a Block of Flats

I. Stanculescu
Consulting Professor, Civil Engineering Institute of Bucharest, Romania

A. Chirica
Assistant Professor, Civil Engineering Institute of Bucharest, Romania

SYNOPSIS : The ground failure presented in the paper, occured in 1986, in the foundation ground, of a ten storyed block of flats, consisting of Bahlui structured dilatant clay, normaly consolidated. The foundation ground rupture, by plastic yielding, begin shortly after an accidental drowning of the basement. Before this accident, the building had not presented any signs of evolutive settlements processes. The paper presents the consolidation measures taken to stop the progressive yielding of the ground beneath the foundations. Results of tests pointed out the dilatant behaviour and the sensitivity to moistening of the Bahlui clays, during the shear process.

INTRODUCTION

In 1986, a block of flats located in Bahlui river plain, near the railway station of Iassy town, suffered a rather peculiar process of foundation ground failure. The construction, consisting of basement, ground floor and 8 floors, having a total weight of about 50,000 kN, was in the final after an accidental drowing of the basement due to the defective installations, presented nonuniform evolutive settlements without any tendency of amortisation. The maximum settlement velocities, established immediately after the start of the movement, were of the order of 5÷7 mm/hour. As a consequence of the nonuniform settlement the construction began to incline visibly (fig.1).

Fig.1 Uneven settlements of the block of flats

On examining the basement rooms in the zone with maximum settlements it was established that the soil under the continous foundations of the construction was rejected (fig.2).

The concrete slabs of the floor broke and they were dislodged , the soil raised in the rooms from the large settlement area and, almost, reached the ceiling. The plan arrangement and the shape in vertical section of the foundations are shown on figure 3. The antisymmetric shape

Fig.2 The rejected soil in the basement rooms toward the large settlements area

of the foundations plan as against the central inertial axis parallel to the construction sides can be noticed. In an open pit situated in the part opposite to the inclination from the nonuniform settlement, it was noticed that the reinforced concrete bearing was detached from the plain concrete foundation (fig.4).

The rejected soil in the basement rooms was formed of black clay fragments with dimensions of order of 3 ÷5 cm and shiny lateral surfaces with striations caused by shearing (fig.5).

GROUND STRATIFICATION

The boreholes and the static penetrometry in points of the construction perimeter helped to determine the stratification strength of the foundation ground. It was established that the microfissured, structured consistent black Bahlui clay on which the construction was founded, has thicknesses of about 4,00 m and followed by sandy layers of higher strength and rigidity along other 4,00 m, after which the stratigra -

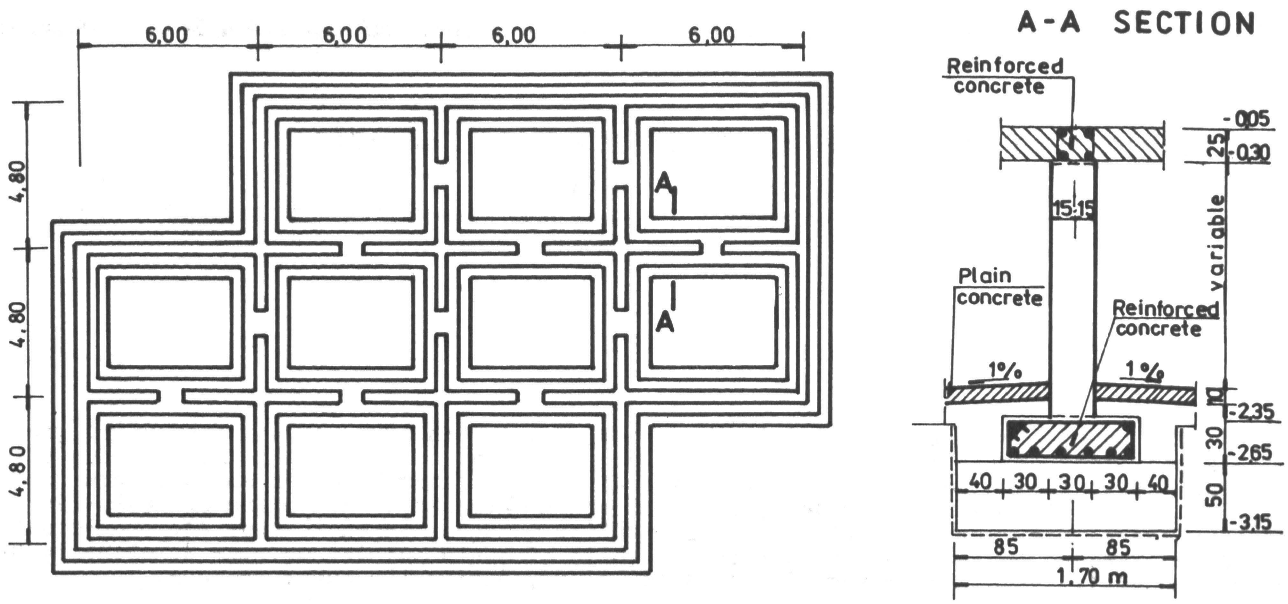


Fig.3 Plan arrangement and shape of the foundations

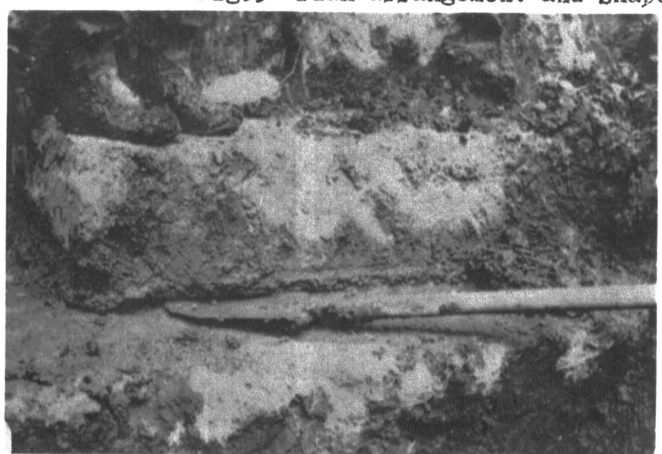


Fig.4 Open space between reinforced concrete and plain concrete foundation, due to uneven settlements

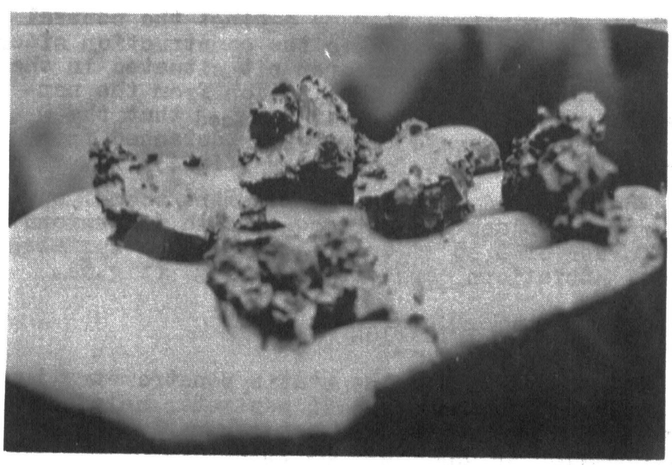


Fig.5 Rejected soil aggregates

phic columns comprises a compact marly clay on great thicknesses, of tens of meters.

MEASURES APPLIED TO STOP SETTLEMENTS AND FOUNDATION SYSTEM CONSOLIDATION

The measures to stop the nonuniform progressive settlements were utterly necessary, especially in order to stop the tendency of rotation around the longitudinal axis of the construction, which process ought to lead finally to its lateral collapse. In the first stage, the measure consisted of stopping the lateral rejection of the earth under the foundation in the rooms situated on the area with great settlements in progress. This was done by means of a screen made of metalic pipes 2" diameter, thrust on the inner contour of the foundation by hammering (fig.6).

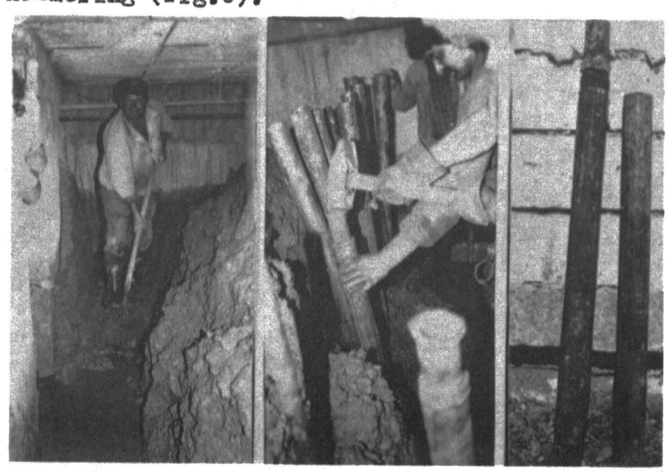


Fig.6 Metalic pipes screen to brake the soil plastic yielding

Thus, an access space was created by excava-
ing the rejected earth only from the founda-
ion surface, without moving this rejected earth
n the central zone, of the rooms. Due to its
eight, that material represented a stabilizing
lement. The pipes were hammered with their peak
own to 2,00 m below the foundation surface in
he three rooms in which the rejection process
as most intense. The work was finished by
ontinuous work in 24 hours, and the settlement
easurement rendered evident its effect, by di-
inishing the maximum settlement velocity to
÷5 mm/day.

Trying to block up the nonuniform evolutive
ettlements, the second treatment stage consis-
ed in reducing the nonuniform settlement rates
y a forced drying of the wet fissured clays,
nder the foundation bottom with quick lime. As
t is known, this substance fixes water chemi-
ally, by hydration, according to the exother-
al reaction :

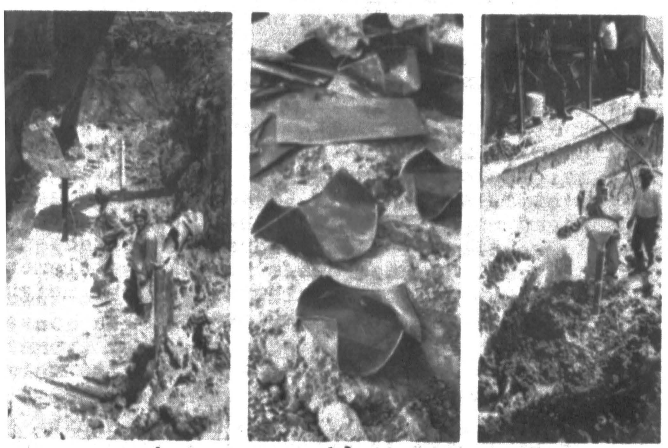
$$CaO + H_2O = Ca(OH)_2$$

ince the atomic weight of (Ca) = 40, of the
xygen (O) = 16 and of hydrogen (H) = 1, it re-
ults that the anhydrous calcium oxide can re-
ain, chemically, a quantity of water of

$$q = (18/56) \simeq 0.32$$

rom the weight of the active substance. The
oundation ground was treated as follows :

The ground was excavated following the cons -
ruction perimeter till the surface of the
lack clay layer in which the foundations were
erformed. At the limit of those foundations,
etal pipes of 100 mm diameter were thrust ver-
ically into the earth by pushing with the sho-
el of an excavator (fig.7,a). The peak of the
ipe reached 3.00 m below the foundation sur -
ace. To prevent the soil from entering the



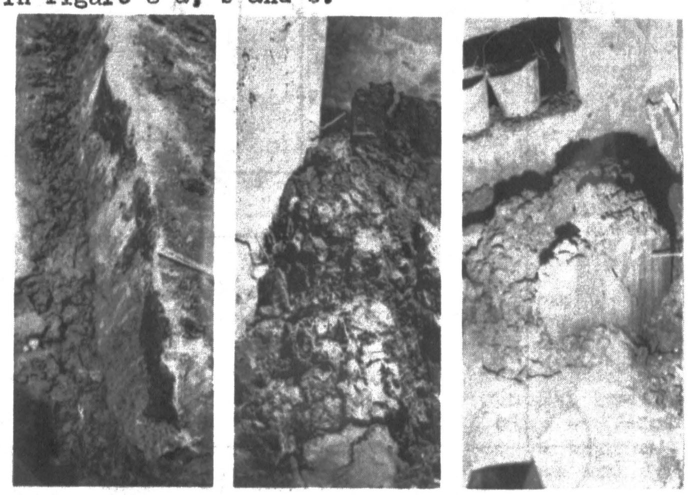
a) b) a)

g.7 Thrust of vertical pipes used to introduce quick lime in the foundation ground (a). Metal sheet bent at corners (b)

pe, its lower end was covered by a metal
eet, bent at its corners (fig.7,b). The quick
me was finely crushed in the ball mill and
en put into plastic bags. Through a funnel
e finely crushed lime was introduced into
e pipe. After filling the pipe , it was ex-
acted by pulling it out using also the ex-
cavator shovel. A treatment cycle was achieved for one point in about 3÷4 minutes. A total of 520 drillings spaced at 20÷30 cm on three parallel rows were performed on the outer perimeter of the foundations. In the first row of drillings, only quick limes was introduced in the second, lime with cement in equal quantities to insure the mix hardening and in the third row, lime with cement and fine gravel (3-7 mm). The two parallel outer rows served to deform the lime columns by thrust and to increase their surface of contact with the ground During the treatment period, ground temperature was noticed to grow in the zone. The work was completed in about 48 hours and its result was the reduction of the maximum settlement rate to about 1 mm/day. The continuation of displacements by the rejection of the ground below the foundation came to put into contact the floor over the basement with the ground entering in the three rooms at the maximum settlement zone. Thus it was necessary to block up the nonuniform settlement. After eliminating some solutions of unilateral supporting of the structure on the marly clay layer, by piles or cast in place diaphragm concrete walls, the adopted solution was that of straightening the inclined construction by a controlled settlement to the opposite side of the inclination and by step by step construction of a general reinforced concrete mat.

The following procedure was applied.

In the basement rooms at the part opposite to the inclination and on the outer perimeter of the construction, local excavations were made till reaching the foundation bottom. The horizontal dimensions the position and execution sequence aimed at causing local yielding and rejections of the foundation ground of the same nature as those who determined the uneven settlements and thus to reduce the construction inclination. For each local excavation, when reaching the foundation bottom level, earth yielding and lateral rejection started as shown in figure 8 a, b and c.



a) b) c)

Fig.8 Yielding and rejection provoked on the outer limit of the foundations (a). Rejection provoked at the limit of the elevator's case (b). Prismatic volume of clay rejected between the elevator's case and the foundation of the outer wall (c) was noticed that by drying the Bahlui clay changes its color, acquiring redish tones which particularity can be explained by the partial passing of the ferrous oxides into ferric components. The presence of the montmorillonite and clorite, makes clay highly hydrophile with great volume variations at humidity variations. The granulometric analysis by sedimentation rendered evident the presence in a predominant ratio (40-60) % of the clay fraction (d < 2μ). The clay plasticity index is $I_P > 40$ % with flow limits w_L = 76-99 % (characteristic values for swelling and high contraction clays). One of the particular features of the Bahlui clay is the microfractural system which delimitates the

the beginning of the test till breaking (open system). The results of the tests on the first group of samples stressed without any water on their contour, are presented in fig.12. Higher values were obtained for the spherical and the limit deviatoric tensor, than in the case of the samples tested with water. This difference is explained as the effect of water drawn by suction into the soil volume, increased by dilatancy.

The variation of the specific volume deformation along the stress paths for the samples tested without any water is shown on fig.13. It can be seen that by increasing the spherical tensor, the dilatancy is less evident due to the structural aggregate shearing. Based on those experi-

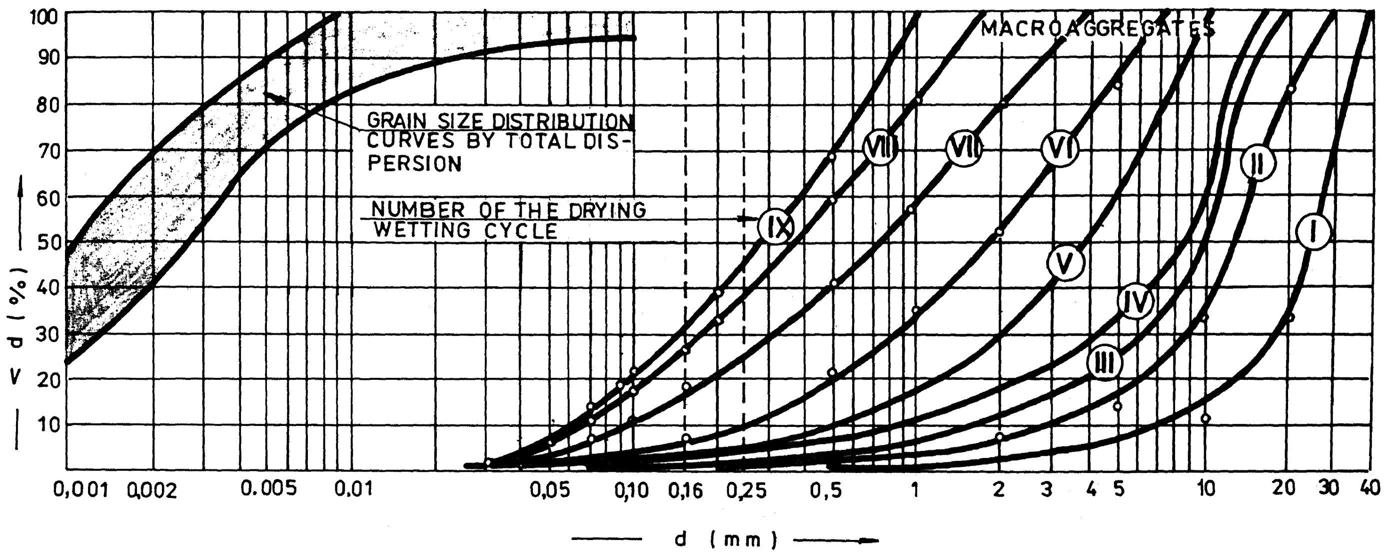


Fig.11 Size distribution of the clay soil aggregates for different cycles of dessication - humidification

structural aggregates of polyedral shapes with sharp edges, of variable sizes. Tests were carried out in order to determine the size distribution of the structural aggregates resulting from the drying-wetting cycles.

Figure 11 shows the size distribution curves for structural aggregates resulting from 9 wetting-drying cycles (I-IX). It can be seen there is a marked difference between these curves and the granulometric composition range of the dispersed material up to isolated solid particles. The presence of the structural aggregates in the Bahlui clay makes the shearing process cause increases of the stressed material volume, by dilatancy. Tests were performed in the triaxial device with imposed stress and measured strain in order to render evident from the quantitative point of view the effect of dilatancy on the volume deformation caused by shearing. The cylindrical clay samples with natural humidity and structure were subjected to increasing triaxial stresses starting from the initial lithostatic stress state. The stress paths were observed till breakage in which both the spheric and the deviatoric tensor increased progressively, linearly. To render evident the effect of water on the strain and failure process, two sample groups were tested (fig.12). For the first group the natural humidity was maintained over the entire stress path (closed system) and, for the second group the samples were brought into contact with a water source on the porous plate surface and on their cylindrical contour, from

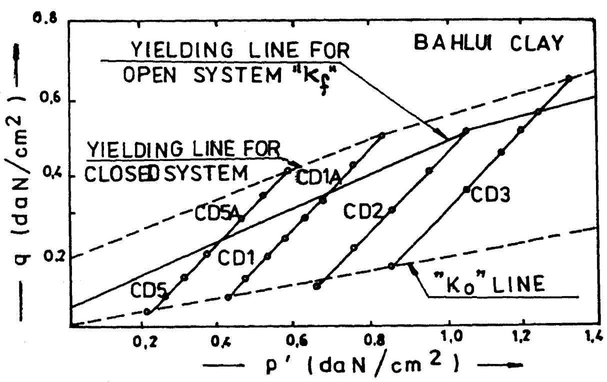


Fig.12 Stress-paths for shearing tests in triaxial apparatus with and without water supply

mental results a scenario could be reproduced in the laboratory of the soil failure process under the damaged foundations. The Bahlui clay samples were subjected in the triaxial device to increasing stresses, by steps of the spherical and deviator tensor (fig.14). At stresses values corresponding to the terminal points of the stress path represented in figure 12, between the failure curves without water (closed system) and with water content (open system), the samples were brought in contact with water. As shown on the diagram of figure 14, the axial strain and swelling process went on under constant stress, until the sample broke, about 215 hours after starting the test. The described phenomenon re-

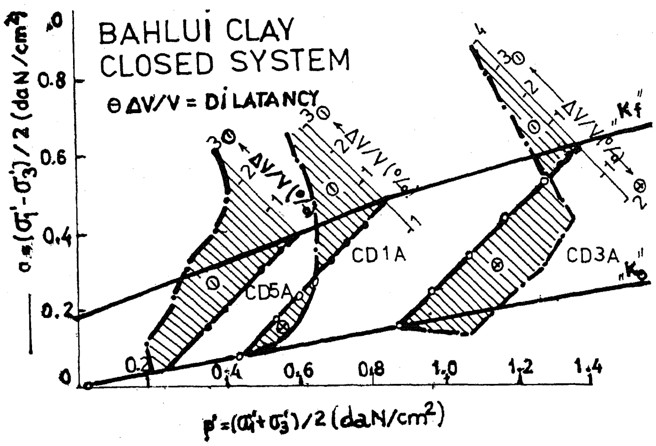


Fig. 13 Volumetric strains variation during the stress paths

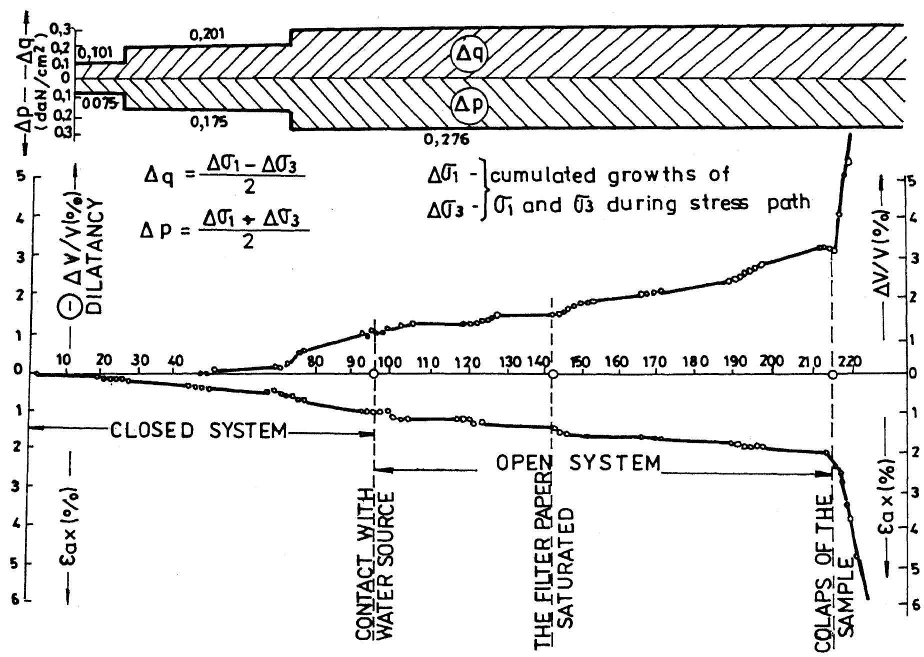


Fig.14 Progressive yielding of the clay soil under constant state of stress and humidification

produced in the laboratory after the accident which occured in the examined construction shows the critical situation of the structured soil becoming sensitive for the water action by dilatancy under the deviatoric stresses action.

This is the case of the soil under the local compression of the foundations with small overload on the basement side. A similar stress situation is represented by the earth located at the toe of deep slopes which presents time failure phenomena. In the same manner the loess has a sensitivity at wetting which means that its deformability increases considerably when the humidity increases. The microfracturated structured clays an similarly sensitivity at wetting in the critical stress state in which the deviatoric tensor is dominant.

The possibility of avoiding the dangerous phenomena like the one described can be avoided by the local correction of the state of stresses in the field, which means to increase the spherical tensor and to decrease the deviatoric one in the critical zone, or by replacing and treating the sensitive soil.

REFERENCES

Chirică A. (1991) - Contributions concerning the influence of cohesive soil macrostructure of settlements and yielding of the foundation ground. Ph.D.Thesis. Civil Engineering Institute of Bucharest.

Stănculescu I. (1987) - From the experience of some difficult foundation works. Technical paper. Proc. of 6th National Conference on Soil Mechanics and Foundation Engineering. Galatzi.