Behavior of the Foundation of Bridge Reinforced by Rigid and Flexible Inclusions

T. Karech A. Noui, T. Bouzid

***Abstract*—**This article presents a comparative study by numerical analysis of the behavior of reinforcements of clayey soils by flexible columns (stone columns) and rigid columns (piles). The numerical simulation was carried out in 3D for an assembly of foundation, columns and a pile of a bridge. Particular attention has been paid to take into account the installation of the columns. Indeed, in practice, due to the compaction of the column, the soil around it sustains a lateral expansion and the horizontal stresses are increased. This lateral expansion of the column can be simulated numerically. This work represents a comparative study of the interaction between the soil on one side, and the two types of reinforcement on the other side, and their influence on the behavior of the soil and of the pile of a bridge.

***Keywords*—**Piles, stone columns, interaction, foundation, settlement, consolidation.

I. Introduction

RAPID urbanization in developed or developing countries involves a densification of constructions such as buildings, major civil engineering works, communication routes, etc. This urbanization involves the increased use of available floor surfaces, sometimes with low mechanical properties such as fine soils or clayey soils, deformable and of low bearing capacity. This problem poses a real challenge for geotechnical engineers in most major cities, such as coastal ones. To overcome these defects, various techniques of soil reinforcement by inclusions have been developed and applied during the last years: rigid inclusions (micro-piles, jet grouting ...) or flexible inclusions (geotextiles, stone columns, etc.) reinforcement technique of low bearing capacity soils with stone columns or piles has been applied in many countries for several decades and has been widely successful, which demonstrates its effectiveness.

Rigid inclusions are used to amplify the initial load capacity of the soil. Used to base point, linear or large surface works on compressible soils of all kinds.

Stone columns consist of reinforcement by compact and incorporate granular material, of a site whose characteristics are insufficient for a direct foundation on the ground of distributed or punctual loads. Delivery with or without injection fluid (consists of air or water).

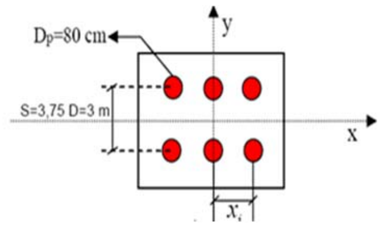
The objective of this work is to make a comparative study in 3D between two modes of reinforcement; flexible and rigid, to analyze the soil-inclusion interaction (flexible and rigid) under load of the superstructure (static load).

T. Karech A. Noui and T. Bouzid are with the University Mostefa Benboulaid Batna2, Department of Civil Engineering, Algeria (e-mail: a_karech@yahoo.fr, karech@hotmail.com, abdelkadernoui@hotmail.com).

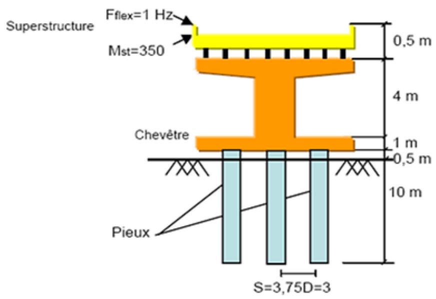
II. Reference Example

The problem retained in this study is represented by Fig. 1. It represents a pile of bridge built over a layer of compressible soil.

The foundation rests on a row of a group of two piles of 2x3 floating inclusions of 80 cm diameter implanted in a homogeneous 15 m deep soil, the spacing between the inclusions is 3 m (3x3, 75 D) [7].



(a) Plan view of model



(b) Cross section of model

Fig. 1 Reference model [7]

The inclusion is embedded in a 1 m thick beam with a length of 10.5 m in the case of the pile, and the distribution mattress used in the case of the stone columns is 50 cm thick and the length of the columns is 10 m. The behavior of the soil is elastoplastic described by the Mohr-Coulomb criterion with an elastic behavior of the superstructure. The characteristics of the soil and the superstructure are given in Table I.

TABLE I
Property of Soil and Superstructure [7]

Material	Density weight γ (KN/m^3)	Module of deformation E (KN/m^2)	Poisson ration ν
Soil	17	2.10^7	0,45
Superstructure	25	8.10^7	0,3

III. Reinforcement by Rigid Inclusion (RI)

This technique consists of vertical inclusions introduced into the soil; descending to a supporting horizon to transmit the charges to the rigid substratum.

The piles are classified according to their natures (wood, concrete, steel), their embodiments (prefabricated, constructed in situ) and load transfer mechanism (friction, tip, friction and tip). It makes it possible to construct works such as road or rail embankments, industrial pavements on poor quality grounds and has the advantage of greatly reducing settlement under load [1], [2], [7].

The piles are placed in the soil either directly under the structure, as in the case of mixed soles, or under a distribution mattress (Fig. 2) [2].

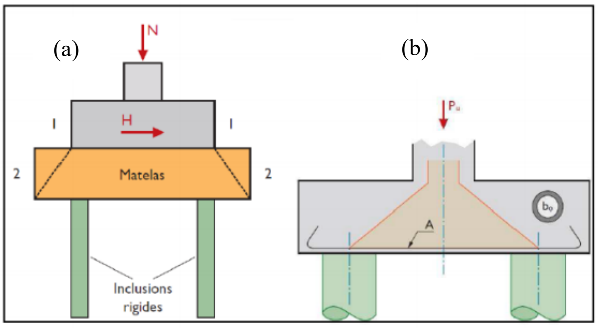


Fig. 2 Rigid inclusion under the distribution mattress (a) and under the mixed sole (b)

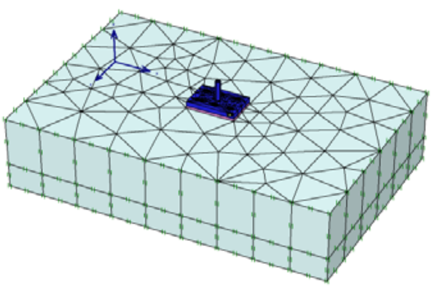
IV. Reinforcement by Flexible Inclusions (FI)

This technique is used to improve soils of poor geotechnical quality by incorporate and compact materials with superior soil characteristics.

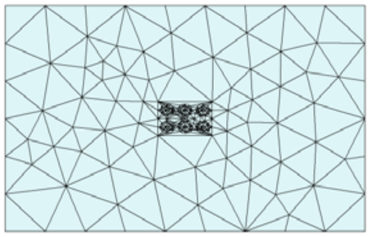
Unlike piles which are connected to the Soles by means of scrap reinforcement, a mattress is used to distribute loads, which is placed between the sol-column complex and the superstructure in the case. In addition, stone columns allow an effective radial drainage to ensure consolidation [3]-[6].

V. Numerical Model

The selected mesh is illustrated in Fig. 3, with 1800 elements and 5678 nodes in the case of piles and 1640 element with 5070 nodes in the case of stone columns; the mesh is refined around the piles because this zone contains strong stress.



(a) 3D model



(b) Plan view of model

Fig. 3 Mesh in numerical of the reference model

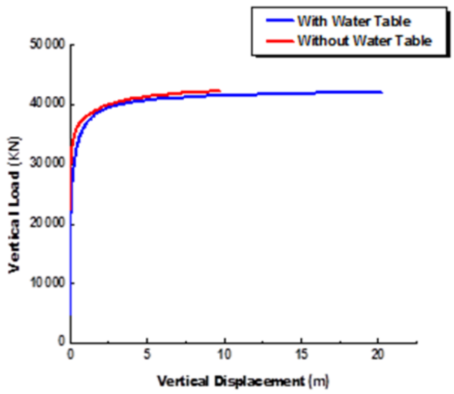
The study was performed for two types of reinforcement case of a purely cohesive soil (C = 50kPa, φ = 0°) and a frictional soil (C = 2 kPa, φ = 30°) to evaluate the influence of plasticity for both soil types on the behavior of the soil-inclusion-structure system, and additional interest to the influence of the absence and the presence of the water table at the level of the surface.

VI. Discussion of the Results

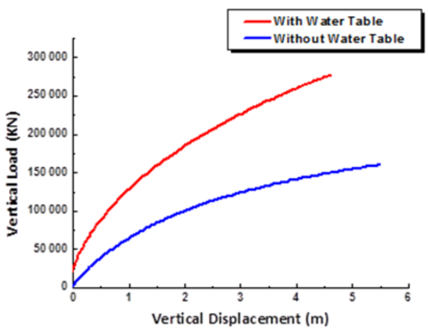
A. Bearing Capacity

1. Rigid Inclusion Case (RI)

Fig. 4 shows the load versus the displacement in the case (RI) for both variants (cohesive soil and frictional soil with low cohesion) with and without the water table.



(a)



(b)

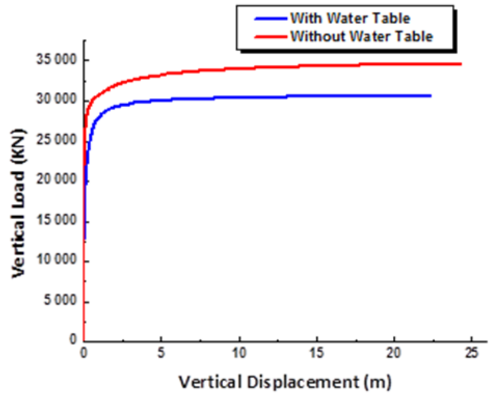
Fig. 4 Load-displacement curve RI, (a) Purely Cohesive soil, (b) Purely frictional soil

The bearing capacity is almost the same either with or without the water table. The difference is that the plastic bearing is important in the presence of the water table for cohesive soil.

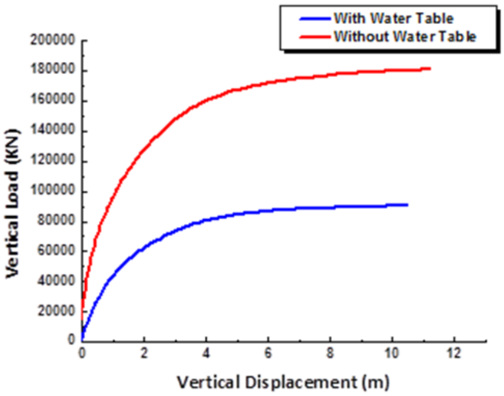
In the case of the frictional soil, a reduction in the bearing capacity is observed in the presence of the water table, it is reduced to about half its value in the case without the water table.

2. Case of Flexible Inclusion (FI)

Fig. 5 shows the result obtained for the same cases cited in rigid inclusion.



(a)



(b)

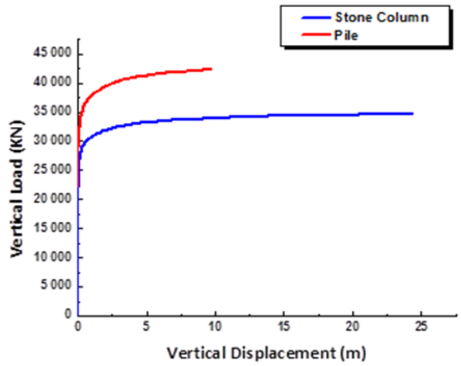
Fig. 5 Load-displacement curve FI: (a) Purely Cohesive soil, (b) Purely frictional soil

In the case of a cohesive soil, the bearing capacity with or without a water table, the difference and hardly 12%, contrariwise, for frictional soil the difference is 50% and always with an important plastic bearing in the cohesive soils.

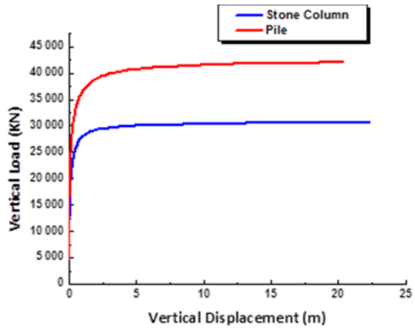
3. Comparison between (RI) and (FI)

- With the water table Purely cohesive and Purely frictional
- Without the water table Purely cohesive and Purely frictional

For both variants, the increase of the bearing capacity by the RI is greater than the FI with the presence of a plastic bearing important for the flexible inclusions.

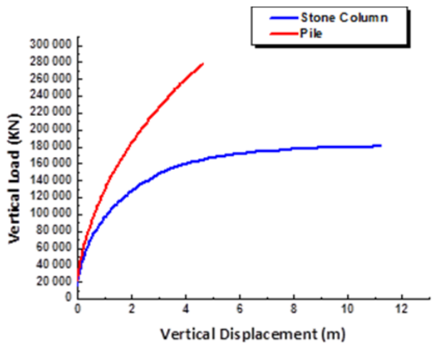


(a) Without Water Table

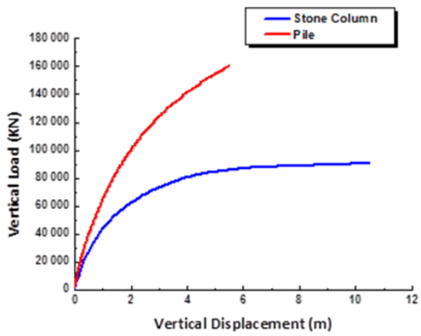


(b)With Water Table

Fig. 6 Comparison between flexible and rigid inclusions: Purely cohesive Soil



(a) Without Water Table



(b) With Water Table

Fig. 7 Comparison between flexible and rigid inclusions: Purely frictional soil

In the case of the cohesive soils, the presence of the water table increases the difference between the value of the bearing capacity (up to 13% without water table and 27% in the opposite case), but this influence is important in frictional soils (35% without water table and 43% with water table).

B. Consolidation

In the case of loaded saturated soils, an increase in interstitial pressure is observed; this increase gives a consolidation settlement at the end and a dissipation of the interstitial pressure which remains dependent on the permeability.

1. Comparison between (RI) and (FI)

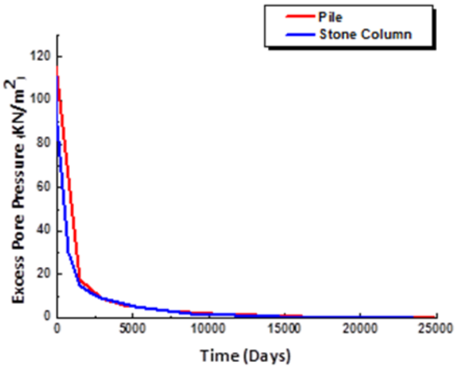


Fig. 8 Variation of excesses pore pressure versus time: Comparison between reinforcement by stone columns and piles

Fig. 8 shows pore pressure versus time for the two types of inclusion in the case of purely cohesive soil.

For the analysis of the consolidation, the same load is applied. In the first eight years the application of load, the excess pore pressure in the case of reinforcement by FI is lower than the one in the RI case. This can be explained by the effect of the drainage of the ballasts, as after eight years, the value of the interstitial overpressure in the piles (RI) decreases and reaches almost the same value as the columns (FI).

The final time of consolidation is in 5 years and 6 months by the ballasted columns and 8 years and 6 months by the piles.

2. Influence of the Diameter of (FI)

Fig. 9 gives the result with flexible inclusion for diameter values (D = 0.80 m, 0.90 m, 1.00 m, 1.10 m and 1.20 m). The increase in the diameter value induces a decrease in the excess pore pressure (Fig. 9) and also the consolidation time (Table II).

TABLE II
CONSOLIDATION TIME IN FUNCTION OF DIAMETER

Diameter (m)	Time of consolidation (years)
0.80	92.03
0.90	92.03
1.00	64.03
1.10	64.03
1.20	64.03

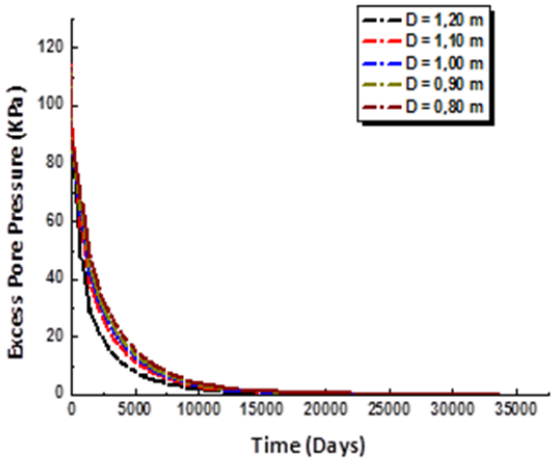


Fig. 9 Influence of the diameter on the excess pore pressure and the consolidation time

VII. CONCLUSION

This comparative study between rigid and flexible inclusions, introduced into the soil and descending to a supporting horizon to transmit the charges to the rigid substratum, has shown the influence of these reinforcements with respect to their stiffness and load transfer mechanism (friction, tip, friction and tip), and the effect on the behavior of the purely cohesive soil or purely frictional, but compressible with or without the presence of the water table, as well as their advantage on efficiently reducing settlements of consolidation time and bearing capacity.

For rigid reinforcement (RI), the bearing capacity increases significantly, but with a plastic bearing less important than the flexible reinforcement.

For flexible inclusions (FI), the time of consolidation decreases with significant values when the diameter of the stone column increases.

The time of implementation and the costs for flexible piles are less important than rigid piles.

In perspective in dynamic analysis, note that flexible reinforcement will play an important role in reducing the phenomenon of soil liquefaction.

REFERENCES

[1] Alia Hatem, (2009). «*Comportement en zone sismique des inclusions rigides. Analyse de l'interaction sol-inclusion-matelas de répartition – structures*». Thèse de doctorat. Université des séances et technologie de Lille.
[2] Buchi Eric (2013). *«Interaction sol-structure: calcul des impédences et effets sur les fondations»*. Projet de fin d'études. INSA de Strasburg.
[3] Corneille Sébestien (2007). *Etude de comportement mécanique des colonnes ballastées chargées par des semelles rigides);* Soutenue publiquement le 25 juin 2007 en vue de l'obtention du titre de, Docteur de l'Institut National Polytechnique de lorraine. Spécialité: Génie Civil – Hydrosystéme – Géotechnique.
[4] Dhouib, F. Blendeau (2005), "Colonnes ballastées*Techniques de mise en œuvre, domaine d'application, comportement, justification, contrôle, axes de recherches et développement*," Presse de l'école nationale des ponts et chaussées.
[5] Dhouib, Stoehr b., Baouche f., Hermges t. (2002). *Étude des massifs de fondations reposant sur sols traités par colonnes ballastées et soumis à des efforts de renversement*. Journées Nationales de Géotechnique et de Géologie de l'Ingénieur, Nancy.

[6] Dhoui A. (2003). *Comportement des fondations sur sols traités par colonnes ballastées sous charge excentrée.*Comptes rendus, Symposium international FONDSUP 2003, Paris, 179- 184.
[7] Mohanad Al Fach (2009). «*Modélisation tridimensionnelle du comportement sismique du système sol-pieux-pont: Prise en compte des non linéarités du sol et du béton*». Thèse de doctorat. Université des séances et technologie de Lille.