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Numerical modelling of rigid inclusion reinforced road platform, under surface loading and mobile loading

Modélisation numérique d'une plateforme de chaussée renforcée par inclusion rigide soumis à des charge de surface et des charge mobile

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ABSTRACT: In the context of the French National Project ASIRI+, the behaviour of rigid inclusion systems with thin platforms has been studied using physical centrifuge models. These systems are particularly useful in cases of road construction on soft soil subjected to significant settlement, or for studying the behaviour of rigid inclusion systems during construction phases. However, these systems differ from classic reinforcement systems with rigid inclusions due to the specificity of the loading. Indeed, on linear infrastructure or circulating platforms, the loadings are limited to small areas, potentially loading only one inclusion at a time and failing to generate a beneficial arching effect. Moreover, these loadings are usually moving over time, which modify load transfer and repartition in the rigid inclusions. To complement the centrifuge model study, we propose a numerical study in this paper to compare results and help analyse the behaviour of these systems. We first discuss the model fitting on the centrifuge results, followed by a parametric study to analyse the effect of key parameters on load transfer and failure mechanisms. Lastly, we developed a model representing the behaviour of these structures under mobile loading. This allowed us to study the evolution of the load transfer mechanism and the elastic-plastic behaviour of the load transfer platform under several loading cycles.

RÉSUMÉ: Dans le cadre du Projet National ASIRI+ (France), le comportement d'un système de renforcement de sol par inclusion rides avec une plateforme de transfert de charge mince a été étudié à l'aide d'un modèle réduit centrifugé. De tels systèmes de renforcement de sol sont particulièrement intéressants pour la construction de routes sur des sols meubles subissant d'importants tassements ou pour l'étude des phases de construction. Cependant, de tels systèmes diffèrent des systèmes classiques de renforcement par inclusion rigide par la spécificité de leur chargement. En effet, sur les infrastructures linéaires ou les plateformes de circulation, les charges sont limitées à des zones restreintes, et ne sollicitent parfois qu'une seule inclusion en même temps, ne créant pas les effets d'arche de report de charge. De plus, ces charges sont généralement mobiles, ce qui modifie la répartition des charges dans les inclusions. Pour compléter l'étude sur modèle réduit centrifugé, il est proposé une étude numérique dans le but de confronter les résultats et d'analyser le comportement du système. Ainsi, dans cet article est présenté le travail de calage du modèle numérique sur les résultats expérimentaux, puis une étude paramétrique sur quelques paramètres clés dans le but d'analyser leurs influences sur les mécanismes de report de charge et de rupture. Enfin, un modèle représentant le comportement de la structure soumise à un chargement mobile est présenté. Il permet d'étudier la variation des effets de transfert de charge et le comportement élastoplastique de la plateforme sous l'influence de plusieurs cycles de chargement.

Keywords: Rigid inclusions; numerical modelling; mobile loading.

1 INTRODUCTION

The rigid inclusion system aims to create a composite soil by including a network of rigid elements (similar to micro-piles) inside the soft soil layer. Such systems are created in order to support buildings and construction in areas of soft soil that are subject to potential high settlement (ASIRI, 2012). In the process, a Load Transfer Platform (LTP) is constructed on top of the composite soil with a granular material. The behaviour of such a system results in an unequal sharing of the surface load between the soil and rigid inclusions. Indeed, the differential settlement between the soft soils and the rigid inclusions creates specific force chains between the granular elements, focusing the load on the rigid inclusions. This effect is known as the arching effect and can be represented in Figure 1.

In 2019, the French National Project was launched with the aim of developing rigid inclusion systems and improving the comprehension of their behaviour. Among the project's works, we focus here on the understanding of rigid inclusion systems under mobile load solicitation. Indeed, the rigid inclusion reinforcement process can be used for circulation platform reinforcement, for example. In such cases, the loads are constituted by trucks or machinery. These conditions might also occur during the construction stage (compaction of the load transfer platform). Therefore, the loads are restricted to a small area and are not always on top of an inclusion or covering several inclusions. Such loading cases do not correspond to classical rigid inclusion cases and cannot generate an arching effect.

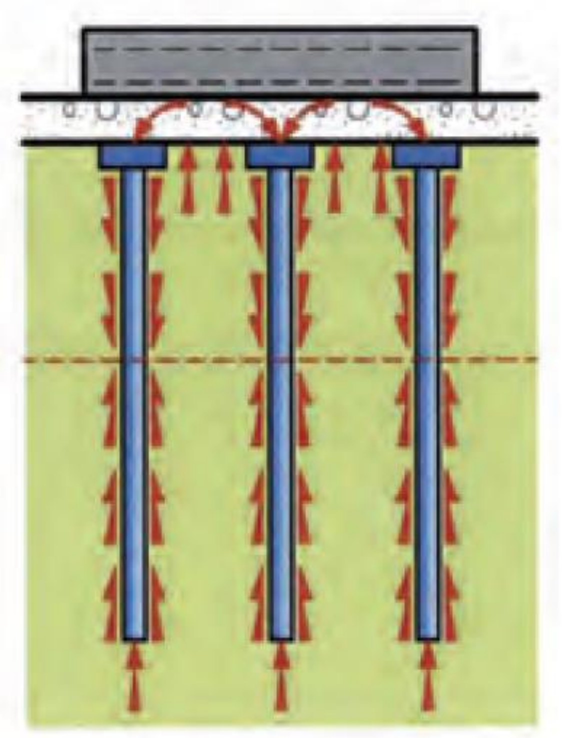

Figure 1. Behaviour of rigid inclusion system (ASIRI, 2012)

2 CENTRIFUGE AND NUMERICAL MODELING

In order to address such loading cases, several models have been studied using a centrifuge test device at the University Gustave Eiffel in Nantes (Corte 1984). The test program consisted of 15 test configurations. A slab was loaded on top of a soil model reinforced by rigid inclusions (Dubreucq et al., 2023). We focus here on two of these configurations: one where the slab was placed on top of an inclusion, and one where the slab was placed between two inclusions (see Figure 2 and Table 1)

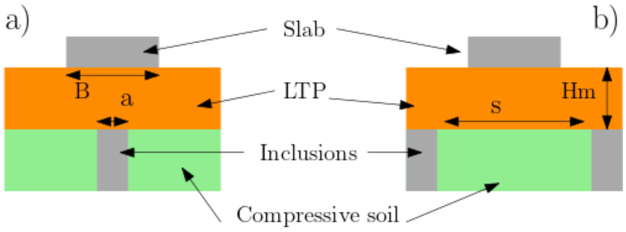

Figure 2. Studied cases a) and b).

Table 1. Model size parameters at prototype scale.

S	a	B	Hm
100 cm	10 cm	30 cm	60 cm

The numerical model is built using the FEM software CESAR LCPC (Humber et al. 2005) at prototype scale. The model is not representative of realistic dimensions, but is designed to explore and understand the behaviour of the system. The model is represented in 2D, with aluminium slab and inclusion. The compressive soil is modelled by expanded polystyrene as it represents an equivalent soil. The LTP is modelled by dense Hostun sand.

The numerical model was built according to the presented geometry. The material parameters were selected as follows: linear elastic for the aluminium elements, perfectly plastic Mohr-Coulomb for the LTP, and hardening Von Mises model for the equivalent soft soil. The parameters of the models were fitted on two preliminary tests of slab only on sand and only on soft soil. The parameters are listed in table 2, and fitting results are presented in Figure 3.

Table 2. Models parameters.

	Aluminium	**Sand**	**Soft soil**
$\boldsymbol{\rho}$	$2700\ kg/m^3$	$1650\ kg/m^3$	$15\ kg/m^3$
$\boldsymbol{E}$	$62\ GPa$	5	$0.8 MPa$
$\boldsymbol{\nu}$	0.24	0.25	0.01
$\boldsymbol{\phi}$	-	36°	-
$\boldsymbol{c}$	-	$3\ kPa$	-
$\boldsymbol{\psi}$	-	23°	-
$\boldsymbol{K_{VM}}$	-	-	$30\ kPa$
$\boldsymbol{H_{VM}}$	-	-	$230\ kPa/def$

Based on the initial models, a second model was built with a mobile load. It represents a rolling load placed on top of the LTP and displaced from one side to another for multiple loading cycles. The mobile load is set to represent a service load at a fraction of the ultimate load determined from previous computations.

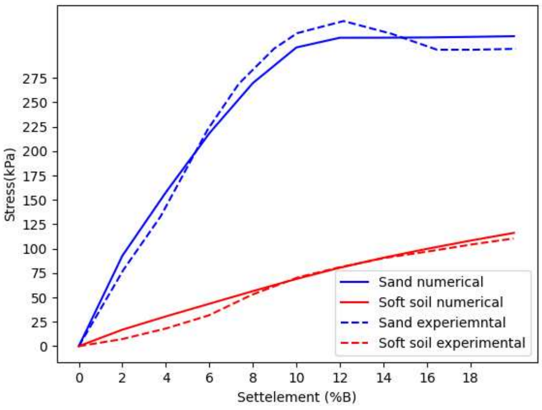

Figure 3. Results of fitting models.

3 RESULTS OF NUMERIALC MODELS

The results of experimental models are not presented in detail in this work.

3.1 First models

The results of models a) and b) are presented in Figures 4 and 5.

Figure 4 presents the shearing band pattern computed for both models. The patterns are the same as those obtained with experimental models.

Figure 5 presents the load-displacement results for both models and both experimental and numerical models. We observe a very good agreement between numerical and experimental results. Moreover, we can observe that the overall behaviour of the system is similar regardless of the position of the slab. We have confirmed this observation with complementary studies with intermediate positions of the slab (not presented here).

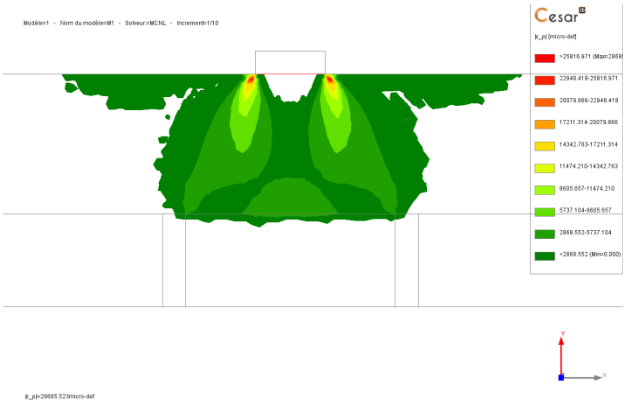

Figure 4. Shearing band patterns on cases b).

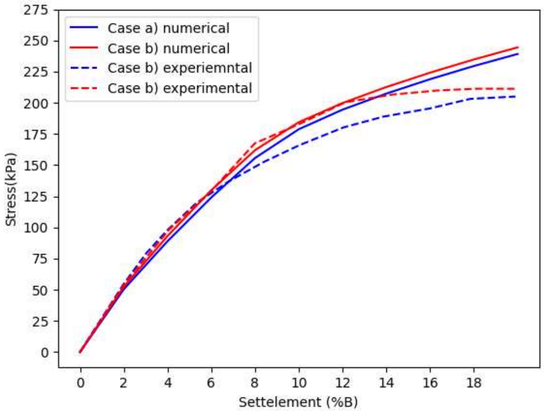

Figure 5. Results for case a) and b).

3.2 Mobile load models

Some results of the mobile loading models are shown on Figure 6. These figures represent the vertical stress at the interface between LTP and composite soil. This figure clearly shows that the arching effect causes the stress to be much more important on top of the inclusion. The weight load of the LTP is focused on the inclusion, and the soft soil is less loaded. However, after the first loading cycle, we observe that the arching effect was destroyed by the mobile loading. Indeed, the load on top of the inclusion is almost null and the load is now sheared onto the top of the soft soil.

This phenomenon can be explained as the mobile loading is not wide enough to transfer its load to the inclusion regardless of its position. Therefore, while between two inclusions, it generates plastic strain, forcing the mechanical interaction between the LTP and soft soil. Mechanically, this results in an unloading of the inclusions.

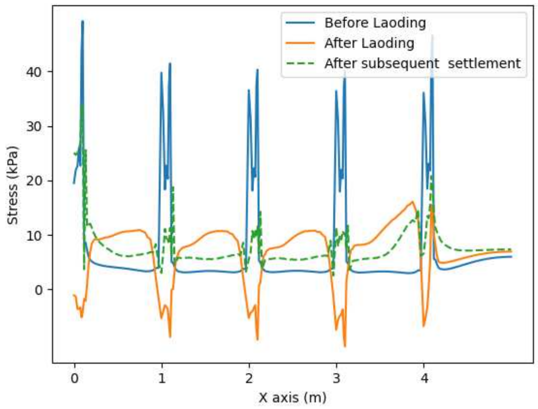

Figure 6. Vertical stress on surface between LTP and composite soil.

3.3 Subsequent settlement

As this phenomenon could be damaging to the arching effect and final behavior of the system, we studied the effect of subsequent settlement. Indeed, we postulate that such behavior will mostly occur during the construction phase of the LTP compaction. Moreover, as it overloads the soft soil, this phenomenon will result in subsequent and continuous settlement of the soft soil, regenerating the arching effect.

This hypothesis was tested by imposing a second settlement phase after the loading cycles. This results in the development of a new arching effect, as shown in Figure 6.

4 CONCLUSION

In this paper, we have presented part of the numerical work prepared in parallel with experimental modelling conducted in the scope of the French National Project ASIRI+. The goal of this work is to model and observe the behaviour of a rigid inclusion system subjected to small slab loading and mobile loading, with a thin load transfer platform. In such cases, the arching effect will not appear as the loading zone is too small to interact with more than one inclusion. Therefore, the resistance of the system should be studied with care. We present numerical modelling which shows good agreement with the experimental results and promising potential. In a second model, we expose the behaviour of a similar system subjected to mobile loading. The mobile loading applied on the LTP disturbs the chain forces in the granular layer and disrupts the pre-existing arching effect in the LTP, which may have an influence on the final behaviour of the system. However, subsequent settlement may regenerate the arching effect.

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