

<https://doi.org/10.32762/eygec.2025.9>

EXPERIMENTAL STUDY OF THE BEHAVIOUR OF THE TREATED LOAD TRANSFER PLATFORM ON RIGID INCLUSIONS

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ABSTRACT

Rigid inclusion (RI) is a ground improvement technique that has been significantly developed in recent years. Granular load transfer platforms (LTP) are commonly used in this technique leading to an increase in the use of natural resources. In this context, soil treatment can be considered as an alternative solution to use the in-situ soil, improve its characteristics and limit the pressure on the granular material resources. As part of the national ASIRI⁺ project, two full-scale tests were carried out to test the behaviour of treated LTP (with and without a working platform) on rigid inclusions. An experimental program was conducted to fully characterize the soil and find the best treatment for the LTP with consideration for the environmental and economic effects. Then, the tests were carried out in an 8m x 8m pit with 16 rigid inclusions of 30 cm diameter and 1 m height. Settlement and stress sensors were installed to monitor the load transfer mechanisms within the treated platform. The instrumentation allowed us to highlight the load transfer mechanisms within the treated LTP and the negative friction along the RI. It showed that the load transfer was immediate in the case of a treated LTP unlike in the case of a granular LTP where the load transfer mechanisms were slightly more gradual. The results indicated that the treated LTP behaved like a rigid slab with two failure mechanisms observed: punching shear (test 1: without a working platform) and bending failure (test 2: including a working platform).

Keywords: soil treatment, load transfer platform, rigid inclusion, full-scale test.

INTRODUCTION

Soil reinforcement using rigid inclusions (RI) is a technique that has become widely used in recent years (Briancon et al., 2020) particularly since the national ASIRI project (2005-2011) was carried out in France to suggest recommendations for the dimensioning of soil reinforcement projects using RI, resulting after 6 years' work in the drafting of the (ASIRI, 2012) recommendations. After five years of using these recommendations, the industry felt the need to provide additional elements to address certain topics that were insufficiently addressed in the ASIRI project such as treated load transfer platforms (LTP). In this context, the ASIRI⁺ project was initiated in 2019 for six years.

The use of granular LTP is quite common in soil reinforcement projects using RI, increasing the exploitation of granular resources (Girout et al., 2013), hence the need to find an alternative solution to improve soil characteristics in situ, therefore, a treated LTP could be considered as a possible solution.

According to the existing state of the art, several authors have studied the behavior of treated LTP

on RI using different setups: simplified physical model (Anggraini et al. 2015) and Mobile tray device (Garcia et al. 2021 and Okyay 2010). However, these reduced-scale centrifuge tests and simplified physical models were not representative of reality due to the geometry of the models, the presence of edge effects, and the use of the mobile tray device that does not take into account the settlement of the treated LTP during the phases of the installation of the LTP and the surcharges. Ferber et al. (2015) optimized the construction of an embankment on RI with a treated LTP, but no instrumentation was installed to monitor load transfer mechanisms.

According to the state of the art, no full-scale test or instrumented structure has been yet presented to study the behavior of treated LTP on RI, hence the decision to carry out two full-scale tests at Cerema's experimental pit in Rouen, France.

MATERIALS AND METHODS

Two full-scale tests were carried out to simulate the real behavior of a treated LTP on RI. The geometrical aspects of the experimental pit,

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the installed setup and the number of RI allow us to eliminate edge effects and simulate real site conditions.

Soil treatment

An experimental campaign was carried out in the laboratory to characterize the mechanical strength of the treated LTP. The LTP is formed from Dieppe silt of type "F1" according to the French guide for embankments and subgrade (GTR, 2023), "A-4" according to the AASHTO, and "CL" according to the USCS.

The treatment consists of 1% cement and 4% lime and was chosen regarding the technical guide of soil treatment (GTS 2000), feedback from ASIRI-partners and the existing state of the art. The cement "CEM II 32.5" is supplied by Calcia while the quicklime is supplied by Lhoist group.

Four mechanical strength tests were carried out to evaluate the mechanical properties of the treated soil at different curing days: a uniaxial compression test (NF EN 13286-41), an indirect tensile test, also called Brazilian test (NF EN 13286-42), a 3-point flexural test (NF EN 196-1) and a triaxial test (NF P94-070). The entire testing procedure, sample preparation and storage, and the various results are presented by Mannah (2025)

Experimental setup

An experimental setup has been developed and tested as part of the ASIRI+ project to simulate the real site conditions. The experimental pit has a surface area of 64 m² and accommodates 16 RI of 30 cm in diameter, 1 m high and installed in a 2 m square mesh (Figure 1).



Figure 1 Experimental pit

The experimental setup consists of several layers modelling a compressible soil, a 40 cm treated LTP, a 1.5 m high backfill and surcharges (Figure 2).

- **Base layer:** It consists of a 2 cm thick layer of wooden grating and a 10 cm thick layer of Biocofra (honeycomb cardboard sheet) that is rigid when it's dry but biodegrades uniformly in the presence of

water. Dissolving this layer will only be used if necessary to impose an additional 10 cm settlement at the end of the test, as this may help us to better understand the behavior of the treated LTP.

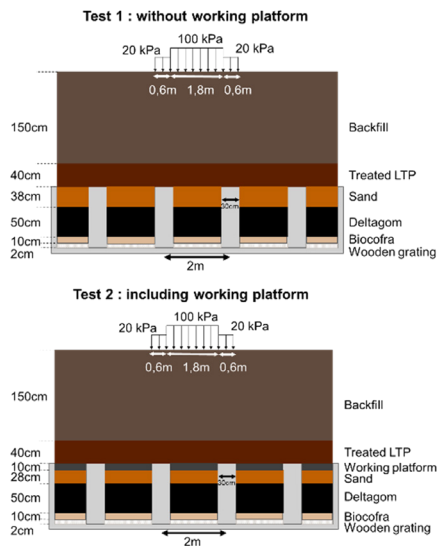


Figure 2 Cross section of the two tests

- **Compressible soil:** It is formed by a combination of two layers, a 50 cm thick layer of Deltagom (rubber aggregate derived from used tires) that is very compressible and a 38 cm thick layer of sand to reach the heads of the RI.
- **Working platform:** A 10 cm working platform formed of Dieppe's silt treated with 2% lime was added under the treated LTP in test 2. The working platform was left for 21 curing days before the installation of the LTP.
- **Treated LTP:** A 40 cm thick LTP consisting of Dieppe silt treated with 1% quicklime and 4% cement was installed, then left in place for 14 and 30 curing days for tests 1 and 2, respectively, before the backfill was installed. Due to the difficulty of treating the LTP directly on the experimental pit, soil treatment was carried out outside the pit, then transported into the pit, where it was compacted in two 20 cm layers to achieve proper compaction.
- **Surcharges:** a 1.5 m high backfill was installed in 3 layers of 50 cm to ensure proper compaction and then left for 1 month to ensure the equilibrium of the system (settlement and stress stability). Then, surcharges were added on the top of the backfill and left for 14 days.

- **Dissolution of Biocofra:** In test 1, the Biocofra was dissolved as expected at the end of the test, whereas in test 2, a water leak occurred next to the pit, resulting in the partial dissolution of the Biocofra during the backfill phase.

The details of the experimental setup, the soil properties and the installation of the layers are presented by Mannah (2025).

Instrumentation

Instrumentation is carried out within the different layers with stress and settlement sensors, which allows us to monitor the load transfer mechanisms, the settlement and the behaviour of the treated LTP.

RESULTS

The water leak in test 2 affected the course of the test and the comparison of results, but a general comparison can still be made of the behaviour of treated LTP and the failure mechanisms.

Stress evolution

Stress sensors installed at the base and the head of the RI, and the compressible soil allow us to verify the stress evolution for both tests during the different construction phases (Figure 3). The results show:

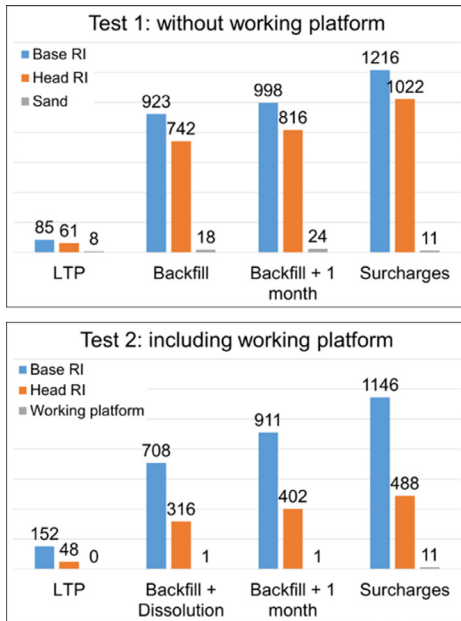


Figure 3 Stress evolution (kPa)

- A stress concentration on the RI in comparison to the compressible soil,

highlighting the load transfer mechanisms within the treated LTP.

- A greater stress at the base of the RI than at the head, due to negative friction along the entire length of the RI.
- The stresses at the head of the RI in test 2 are half those of test 1, due to the addition of the treated working platform. This rigid soil layer takes up some of the stress around the RI head, and transfers it to the base by negative friction, which explains the closer stress states at the base. In most construction projects, the efficiency of a system is evaluated through the stress efficiency presented in (ASIRI, 2012), which is not representative of reality in this case.
- After backfilling, a stress of 742 kPa was measured at the head of the RI in test 1. During the 1-month pause, it increased by 10% to reach 816 kPa. This test was compared with the one carried out by Briançon et al. (2024) using a 50 cm granular LTP with the same experimental set-up used in our test. The results show that during the 1-month pause, the stress increased by 40%, highlighting different load transfer mechanisms.

Settlement evolution

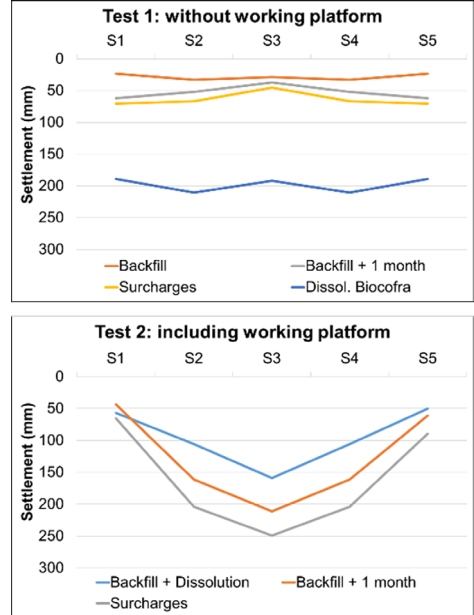


Figure 4 Settlement of the treated LTP

Settlement sensors installed on the various soil layers enabled us to verify the behaviour of the system. The results show that all the layers

settled homogeneously (same trend), indicating two possible failure mechanisms: punching shear or bending failure in the middle of the LTP (Mannah, 2025). To further verify the failure mechanisms, the settlement at the top of the treated LTP is shown in Figure 4, through the various settlement sensors installed (S1, S2, S3, S4 and S5). The results show two different failure mechanisms: punching shear is observed in Test 1, with 20 cm of punching measured after the Biocofra dissolution phase, while bending failure is observed in Test 2, with maximum settlement in the middle of the pit of the order of 25 cm.

Compaction quality

The compaction quality of the treated LTP was verified using a Clegg hammer that measures an average CBR value (Figure 5). The results show that for test 1 and after curing of the treated LTP, a value of 41 and 77% is measured between the RI and at the head of RI respectively, highlighting the presence of "hard points". After LTP failure, a drop in value was observed at the head of the RI (19%), while the rest of the unstressed LTP continued to cure, which explains the increase in value (65%). In test 2, the working platform ensured homogeneous compaction (close CBR values after curing at the head and between the RI: 53 and 56%). Due to the bending failure that occurred, the entire LTP was solicited, and a drop in this CBR value was observed over the entire LTP (42 and 12%).



Figure 5 Settlement of the treated LTP

Failure mechanisms

- Test 1: a 20 cm punching shear failure is observed, with an additional 10 cm of crushing at the level of the RI heads. This failure mechanism is also verified visually and by topographic survey (Figure 6).

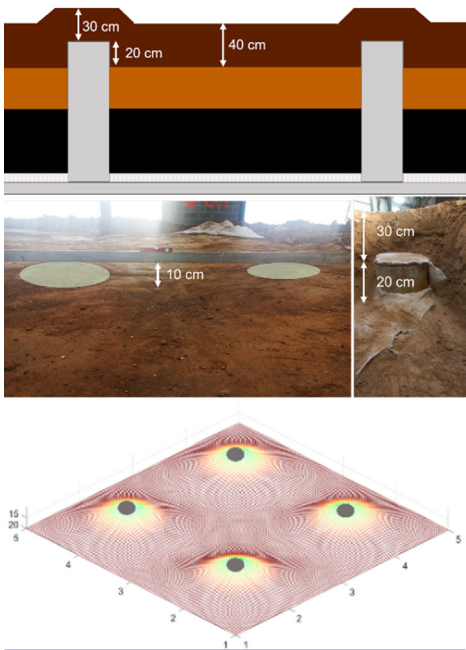


Figure 6 Failure of the treated LTP in test 1

- Test 2: a bending failure is observed with 8 cm of punching at the heads of the rigid inclusions and 25 cm of settlement in the middle of the treated LTP (Figure 7).

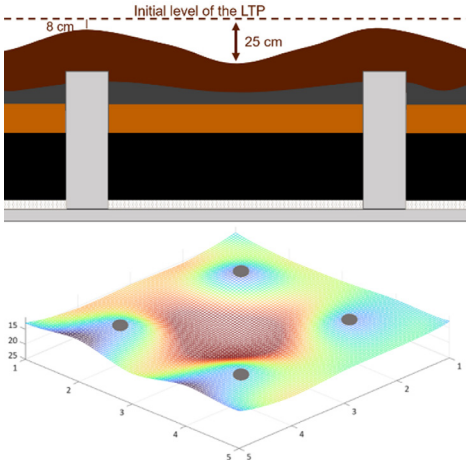


Figure 7 Failure of the treated LTP in test 2

CONCLUSIONS

As part of the national ASIRI+ project, two full-scale tests were carried out to test the behaviour of a treated LTP on RI. The results show that the load transfer is immediate for a treated LTP, whereas for granulated LTP, it is a little more gradual. The treated platform behaves like a rigid slab, with two observed failure mechanisms: punching shear in test 1 and bending failure in test 2. The results show that stress efficiency may not be the best parameter for assessing the efficiency of a system, and settlement efficiency should be considered. Finally, the working platform modified the LTP's behaviour, ensured its homogeneous compaction and reduced the "hard points".

ACKNOWLEDGMENTS

This work was carried out as part of the national ASIRI+ project. The authors would like to thank all the members of this project for their support.

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