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The environmental advantage of bi-directional pile testing related to traditional top-down testing

L'avantage environnemental des essais bidirectionnels sur pieux par rapport aux essais traditionnels par chargement en tête

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ABSTRACT: Together with the constant preoccupation with the safety standards of new structure's foundations the worldwide awareness of climate change continues to increase, making these two elements together with costs the biggest parameters for any foundation project. From the beginning of any foundation project the methodology for a full-scale static load testing program can already optimise many of the requirements in terms of costs and safety, however, only now the environmental optimisation is truly valued. The bi-directional load testing method, by eliminating the reaction structures of the traditional top-down testing methodology, allows the reduction of the overall carbon footprint of the testing program in the most efficient, safe and cost-effective manner for all types of foundations, particularly for larger test loads. The benefits of using bi-directional load tests and how effective they are at reducing carbon emissions will be described. The inclusion of some case studies will illustrate the reduction of CO_2 for (bi-directional) static load testing of foundations in general.

RÉSUMÉ: Parallèlement à la préoccupation constante des normes de sécurité des fondations des nouvelles structures, la prise de conscience mondiale du changement climatique continue d'augmenter, faisant de ces deux facteurs, ainsi que des coûts, les paramètres les plus importants pour tout projet de fondation. Dès le début d'un projet de fondation, la méthodologie d'un programme d'essais de chargement statique à grande échelle permet déjà d'optimiser de nombreuses exigences en termes de coûts et de sécurité, mais ce n'est qu'aujourd'hui que l'optimisation environnementale est réellement appréciée. Du fait de l'élimination des structures de réaction nécessaires à la méthodologie d'essai traditionnelle, la méthode d'essai de chargement bidirectionnelle permet de réduire l'empreinte carbone globale de l'essai de la manière la plus efficace, la plus sûre et la plus rentable pour tous les types de fondations sur pieux, en particulier pour les charges d'essai plus importantes. Les avantages des essais de charge bidirectionnels et leur efficacité en matière de réduction des émissions de carbone seront décrits. La présentation de quelques études de cas illustrera la réduction des émissions de CO_2 pour les essais de chargement statique (bidirectionnels) des fondations en général.

Keywords: Foundation optimisation; bi-directional static load testing; Osterberg cell; decarbonisation of concrete pile foundations.

1 INTRODUCTION

When bi-directional load testing was first brought into pile testing environment, J. Osterberg (1991), predicted savings to the piling world would be in the billions of dollars with the possible reduction of pile size and concreted length for many major projects. As professor Osterberg put it, 'the most economical, functional and practical solution should be sought, followed by a study of how costs can be cut', however at that time he couldn't predict how valuable the bi-directional load testing method would be to reducing the CO_2 emissions for the construction industry.

The current paper is written with the assumption that the readers already understand the correlation between preliminary foundation testing, efficient dimensions of the foundations and the consequent reduction of CO_2 emissions. The focus will be on how the bi-directional load testing allows for a greater reduction of the CO_2 emissions in comparison to other full scale loading methods.

2 PILE DESIGN TESTING PROCESS AND FOUNDATION OPTIMISATION

Ideally, preliminary tests should be undertaken long before the working foundations are constructed, giving designers the chance to re-evaluate their designs and reduce the conservatism that is often introduced in the design due to uncertainties of construction and soil characteristics. The designs are often optimised to obtain an adequate safety factor and the most cost-effective foundations possible for the specific project. However, with the realisation of current damages to our planet provoked by the CO_2 emissions the designers should also take into consideration the environmental element of the project.

When efficiently used, the data obtained from a foundation testing program will allow the possible reduction of the foundation element dimensions and subsequently reduce the CO_2 emissions originating from the reduction of concrete used and equipment usage.

Not only during the actual foundation works are the CO_2 emissions potentially reduced. CO_2 emissions can be further reduced when the bi-directional static loading test method is selected instead of the traditional top-down testing.

3 BI-DIRECTIONAL STATIC LOAD TESTING METHODOLOGY

The bi-directional pile load testing utilises an individually calibrated hydraulic sacrificial loading device (Osterberg Cell® or O-Cell®) installed within the foundation unit. Working in two directions, upward against side-shear resistance and downward against side-shear and end-bearing resistance, the device automatically separates the resistance and displacement data for each component of the pile. By virtue of its installation within the foundation element, the load test is not restricted by overhead structural beam limits and reaction piles. Instead, the device derives all reaction from the soil. End bearing and lower side shear provide reaction for the upper side shear portion of the load test and upper side-shear provides the reaction for the end bearing and lower side-shear portion of the load test.

Once the O-Cell system has been installed within the pile shaft and the concrete has reached sufficient strength, the test can commence. Strain gauges are connected to a data logger (Figure 1) and the system can be run under computer control. When the load cells are first pressurised, the load applied will break temporary welds to prevent the cells from opening prematurely during assembly and form a horizontal separation across the pile at the load cell location.

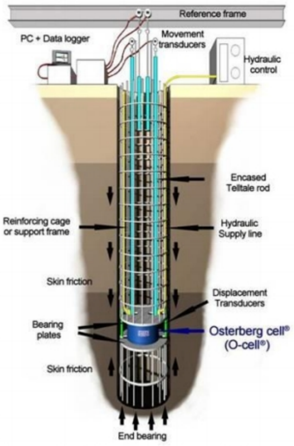

Figure 1. Schematic of a Bi-directional loading test (Fugro).

Once this is done, the test can be performed much the same as a top-down test, by applying the load in stages and measuring movements of each of the components. Testing schedules can be adopted from standard procedures or by recommendation.

4 TRADITIONAL TOP-DOWN TESTING

For the execution of a top-down test a reaction system above the foundation element has to be assembled, with the use of anchor piles combined with loading frames or the use of kentledge blocks.

For a pile/barrette with high loading, in the 10s of MN, a test might require 6 or even more anchor piles These additional anchors require drilling and constructing with steel and concrete, increasing the number of activities, material delivery and its consumption.

A traditional top-down loading system requires a large frame which needs to be constructed with multiple steel beams. The larger the test load requirement the larger these reaction structures need to be. These require to be transported from depot to site and a crane is required to erect the structure, which can be as tall as a 3 story building or more when the loads are as high as 40 to 60 MN.

5 ENVIRONMENTAL COMPARATION

In the following chapter we present a comparation from an environmental point of view between the two

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foundation testing methods with the related CO_2 calculations and with project examples.

5.1 Concrete cut-off level in top-down testing

In a traditional top-down loading test the top of concrete needs to be at ground level or above, often with an additional pile cap. In contrast, for a bi-directional loading test, the CO_2 emissions can be reduced as the necessary volume of concrete can also be reduced if the concrete is not up to ground level.

As an example of this, a project executed in Switzerland included the testing of three 2800x800 mm barrettes where the concrete cut-off level was left on average at 12.3 m below ground (Figure 2, shows the empty panel is backfilled with dry sand). The possibility of leaving the concrete level at the desired cut-off elevation allowed a saving of approximately 82.66 m^3 of concrete. Assuming the Carbon Factor of 212 $kgCO_2e/m^3$ of CEM III/A GGBS (50%) based on the Inventory for Carbon and Energy (ICE) database, 17 TN of CO_2 were saved.

Figure 2. Bi-directional loading test on a pile with concrete cut-off level 12.3 m below ground level (Fugro).

5.2 Reaction structures and anchor piles

As described in section 4, a traditional top-down test requires external reaction structures, like a combination of anchor piles and reaction frames. The loading frame observed in yellow in Figure 3 is a good example of the dimensions and necessary material for reaction beams and anchor piles The CO_2 emissions originated by the production of these structures should be also taken into consideration.

Even if the multiple reuses of the structures on different tests can offer a sense of economic savings, the same isn't felt in terms of the environment as the transport and handling of these assemblies produces CO_2 by the combustion of fuel.

Together with transport and construction of the different reaction structures, the requirement to construct an extra number of piles to serve as anchors, increases the CO_2 emissions related with this type of test. An additional 4 anchor piles for a typical top-down test may not seem much in the total scheme of things but that might be an additional 400 m^3 for the concrete alone on deep large diameter piles, equivalent to more than 80 TN of CO_2. That is without the extra rig emissions for drilling the anchors, concrete and steel transportation and other auxiliary operations. Concrete emissions might be many times as much for high load testing of barrettes and larger piles.

Compared with a bi-directional static load testing the extra construction materials, excavation works and concrete for a top-down load test are avoidable producers of CO_2.

Figure 3. 30 MN top down reaction beams on a barrette test with multiple anchor piles (Fugro).

5.3 Transport for a kentledge test

If in the previous top-down testing method we could associate most of the unnecessary CO_2 emissions with the necessity to construct anchor piles, for a test using kentledge the CO_2 emissions originate from the transport and handling the heavy concrete blocks that will act as reaction system.

It is easily understandable by observing Figure 4 the number of trucks necessary to transport all the blocks. It is also important to note that the CO_2 emissions will directly increase with the requirements of the test load (higher the test load = more blocks needed) and added to this the distance between the depot and site. If we imagine that some remote sites can be more than 1000 km from the depot (example: Mohembo Bridge project and depot in Gaborone – Botswana), we can understand how the reduction of this transport can help reduce the CO_2 emissions.

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Figure 4. Loading test using kentledge Dubai (Fugro).

In comparison, it is possible to observe in Figure 5 the equipment necessary, including O-Cells® and measuring equipment, for a bi-directional loading test designed to reach 70 MN. All the equipment was shipped via air to the closest airport and transported easily.

Figure 6, illustrates a typical test setup of a bi-directional loading test where the necessary reference beam was set over two concrete blocks. The final setup for a bi-directional pile load test may also require the use of short-term lifting equipment, it is important to notice that the same setup observed could be used in any test regardless of loading capacity, from 1 MN to over 300 MN. The test can also be performed offshore where the possibility of using top-down techniques becomes far more difficult, and substantially more expensive.

Figure 5. Instrumentation used for a designed 70 MN load test in a barrette (Fugro).

Figure 6. Bi-directional loading test underway (Fugro).

6 CONCLUSION

The bi-directional loading test was already a more economical, practical/functional and safer option over the traditional top-down loading method and with the information shared in this paper it is also noted that the bi-directional loading test is also a better environmental alternative, either when compared with a loading beam plus anchor piles or a kentledge system.

The current European and global norms have a clear goal of decreasing the CO_2 emissions and the construction sector, as one of the biggest producers of CO_2, should now give the same value to the environment as it gives to cost/profit, safety and time. For a preliminary foundation testing program or for proof tests on working piles (as post test grouting can restore the integrity of the structure) the bi-directional loading test will fulfil all those requirements, as shown in a few project examples.

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