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The carbon footprint of bi-directional static load testing and its potential to help reach the Net-Zero Target

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ABSTRACT: The net-zero target strives to achieve net-zero greenhouse gas emissions across the value chain in the construction industry (in the EU) by 2050 to create a safe and livable world. As part of this initiative, the correct approach for (bi-directional) testing foundation elements is very important and can make the difference, by using unique pile testing data collection. The inclusion of studies shall illustrate the importance of choosing the right testing method for foundation testing. The environmental optimization of static (bi-directional) load testing will be described, which will reduce the carbon footprint and be a milestone in the industry towards net-zero greenhouse gas emissions. Based on Fugro`s geo-data, this paper presents a pile testing database and predicts a potential green future replacing the worst offender, cement, with instrumented test piles. Bi-directional foundation testing was designed and developed in-house in the nineties of last century and is already proving to be a great success in comparison with traditional top-down testing. This innovative idea helps reduce cement consumption and CO2 emissions, getting us closer to achieving our sustainability targets and contributing to a safe and livable world.

KEYWORDS: foundation optimization, bi-directional static load testing, Osterberg Cell, Net-Zero target.

1 INTRODUCTION

Bi-directional load testing, first introduced by J. Osterberg in 1991, was initially recognised for its potential to generate substantial cost savings in the piling industry estimated in the billions of dollars. At the time, however, the broader environmental benefits of the method, particularly its role in reducing CO_2 emissions within the construction business, were not yet fully appreciated.

With the realisation of current negative impact. damages to our environment caused by the CO_2 emissions. the engineers should also take into consideration the environmental element of the project.

The current paper is researching the carbon footprint of a bi-directional static load test and comparing it with traditional top-down testing method. The aim is to get a better understanding of the different impacts on the environment of both methods. It is assumed that the reader already understands the advantages regarding safety, precise data collection, more information on pile behaviour and the economic reasons behind bi-directional testing. The focus in this paper is limited to the saving of CO_2 emissions and to help reach dedicated environmental goals.

2 TEST LOAD CATEGORIES IN FOUNDATION TESTING

One of the key data in pile testing is the applied test load. We created three categories as they all show different market behaviour therefore, they need to be analysed separately and with a different approach. The three categories are as follows:

Testing with low (I) test loads where test loads are below 3,000 kN, middle (II) where the test loads ranging from 3,000 kN to 15,000 kN and high (III) test loads where the test loads range 15,000kN to 320,000 kN+.

This paper will not discuss the overall potential in foundation test for carbon footprint reduction regarding the fact when efficiently used, the data obtained from a static load test 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. This paper will discuss the environmental advantage of bi-directional testing in relation to traditional top-down testing in 3,000 to 15,000 kN.

Category (I) is mainly tested top down. Bi-directional testing in this range is preferred if safety is highly valued and/or if more information about the pile behaviour is sought.

Category (II) load range is the main focus of this paper as it reflects a range where engineers encounter pronounced ambiguity on

whether to use bi-directional testing or the top-down method. The aim is to show the carbon footprint of bi-directional testing and compare it with the alternative if the engineer decides to test otherwise.

In the category (III) range, there is no other real alternative than bi-directional testing. Hence, this paper will not focus on this category as in this range the only reasonable and practicable choice is bi-directional testing and therefore the low carbon footprint including all other advantages are given for the foundation testing.

3 REAL LIFE DATA BASE USED FOR ANALYSES

To gain real life data and as accurate as possible, a special database was used thanks to Fugro which included 634 pile tests in a certain region where all pile tests were registered with in the analysed time frame.

The database of 634 pile tests provided is first arranged according to the test methods as given in Table 1. Lateral-Push testing will not be discussed in this paper as there is no real alternative to choose from when performing this type of test. Dynamic testing is also excluded as it is not a static load test. The majority (85%) was performed as Top-down tests, around 5% as Pull-out and less than

3% as bi-directional load tests (Osterberg Cell, *O-Cell ® tests)*. From all the Top-down tests, 391 falls under Category II (3,000-15,000kN). The majority of these piles (65%) have a diameter of 800mm as shown in Figure 3, and 73% were tested with a load up to 3,500kN. We can deduce from the data, that piles with a diameter of 800mm and a loading up to 3,500kN were the majority of the tests. Therefore this will be the base for the analyses of the comparison.

Table 1. *Summary of data base of 634 pile tests.*

Type of test	quantity
Lateral-Push	2 piles
Top-down	540 piles
Dynamic	15 piles
Pull-out	32 piles
Bi-directional	17 piles
Lateral-Pull	28 piles

ANALYSES OF STATIC LOAD TESTING

To execute a top-down test, a reaction system above the foundation has to be installed, either with the use of reaction piles, anchors or the use of kentledge blocks.

During the execution of a bi-directional load test, the end bearing and lower side shear components of the test pile act as a counteracting force to the upper side shear. Consequently, the pile itself functions as a self-contained reaction system, as illustrated in Figure 1.

Working in upward against side-shear resistance and downward against side-shear and end-bearing resistance (if considered) the technique automatically separates the resistance and displacement data for each component of the test pile.

By virtue of its installation within the foundation element, the load test is not restricted by overhead structural reaction

beams and reaction piles. Instead, the test pile itself becomes the reaction system as shown in Figure 1.

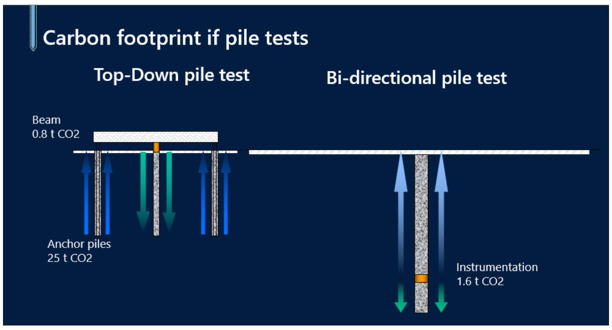

Figure 1. *Schematic of a Bi-directional test in comparison with top-down pile test.*

Once the fully instrumented test pile is installed, the test can be performed similar to as a top-down test, by applying the load in increments and measuring movements of each of the components. Testing schedules can be adopted from any standard procedure.

Details for the instrumentation of a typical bi-directional test setup with O-Cell ® technology is shown in Figure 2.

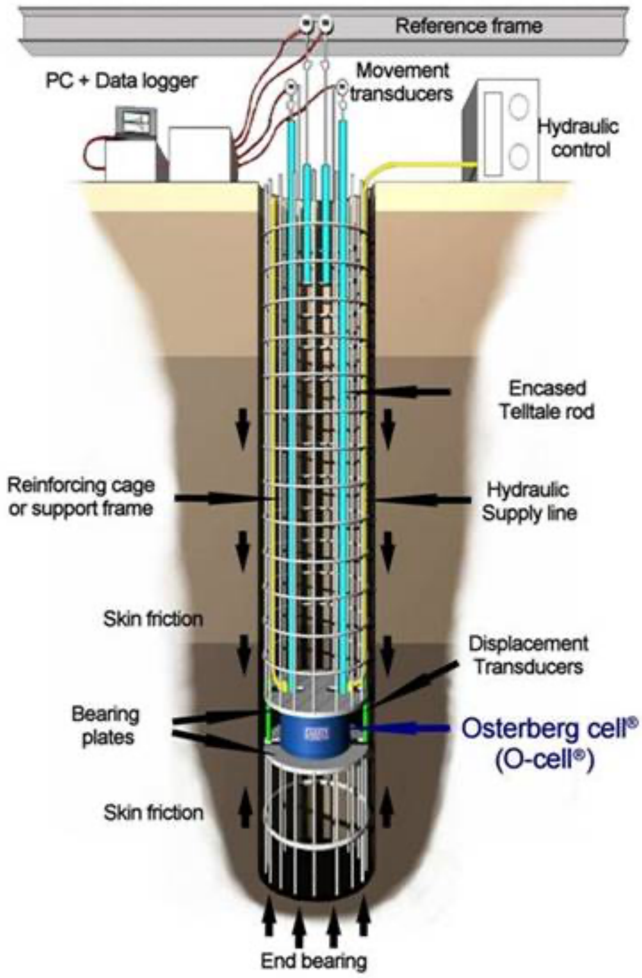

Figure 2. Schematic of a Bi-directional loading test (O-Cell ®, Fugro)

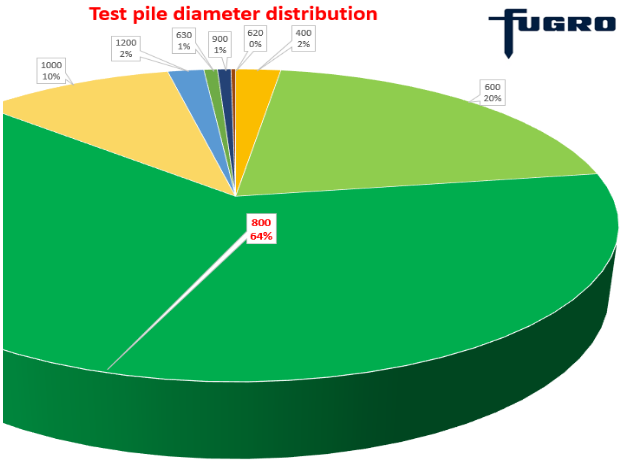

Figure 3. Fugro data base: Test pile diameter distribution

4 ENVIRONMENTAL COMPARATION

In this chapter the comparison - on both lines from an environmental point of view is shown between the two foundation testing methods with the related CO_2 emissions in the middle range, category (II).

4.1 *CO2 emission for each work step*

To present the difference in carbon footprint for top-down and bi-directional testing requirements for mobilisation, drilling equipment and site works has been excluded. The focus will be on the matters that are different in each method. Table 2 shows a typical pile test procedure for a test pile with a diameter of 800mm, 20m deep and a 3.5MN test load, including, the carbon footprint for each relevant work step.

For the bi-directional Instrumentation a 240 mm O-Cell (238 kg CO_2), instrumentation (120 kg CO_2) and hydraulic pipes
(60 kg CO_2) was taken in account. The travel of the O-Cell and instrumentation (800 kg CO_2), personnel travel (200 kg CO_2) and extra working days (200 kg CO_2) was included. These producing in total of 1.6t CO_2 for each test pile.

For the top-down pile testing method concrete (14,000 kg CO_2), steel (11,000 kg CO_2) and reaction beam mobilisation (800 kg CO_2) are taking in account. These producing in total of 25,8t CO_2 for each test pile.

When eliminating the reaction piles by using pre-assembled instrumented test piles capable of bi-directional load tests, we not only gain more data about the pile behaviour (separate load-movement curve for below and above the O-Cell) but also lower the CO_2 emission by making a environmental friendly choice. In only one test with parameters named above, we can lower the CO_2 emissions by 25t if not using reaction piles and 0.8t leaving the reaction system behind. The instrumentation of the bi-directional test piles does require some additional attention and about 1.6t CO_2 emission, but it is only 6% of what top-down would require in addition.

To show an average annual saving of CO_2 in Europe changing to bi-directional testing where possible, we need to project the area in respect of test pile number of the database (93,000 km2 => 63 piles annually) to the size of Europe (10,180,000 km2 6,896 piles annually). Potential saving on 1 test pile is 24.2 ton of CO_2. 82% of piles analysed in the data base could be replaced with bi-directional load testing method, that gives us annual saving of 1,254 tons of CO_2 emission in the given area and 136,846 tons of CO_2 annually saving in Europe.

Table 2. top-down vs. bi-directional method`s carbon footprint (Fugro)

procedure	Top-Down Carbon footprint	Bi-directional Carbon footprint
Pre poject documentation	same	same
Instrumentation of test pile	0	1.6t
Site setup	same	same
Test pile installation	same	same
Reaction pile installation*	25.0t	0
Installation of reaction beams	0.8t	0
Performing piles test**	same	same
Reporting	same	same

*including demobilisation

**top-down is performed with oil, bi-directional with water meaing no pollution.

In comparison, it is possible to observe in Figure 4 the setup necessary, including measuring equipment, for a bi-directional loading test designed to reach 48 MN compared to just 20 MN top-down test. Bi-directional testing not just requires less space for the setup but offers a safe environment around the test pile during the static load test. It can be performed next to a busy road, with in restricted area with the highest safety standards, congested sites, near shore or offshore. 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 technique becomes far more difficult, impractical and substantially more expensive.

Figure 4. 48MN Bi-directional test vs. 20 MN top-down method. (Fugro)

4.2 *Additional CO2 emissions by virtue of the methods*

Concrete level: In top-down load tests the top of concrete needs to be at ground level, often with specially formed pile caps. In contrast, for a bi-directional load test, the CO2 emissions can be reduced as the necessary volume of concrete can also be reduced if the concrete is not required to be cast to ground level.

Reaction beam: Even if the multiple reuses of the structures of reaction beam 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 produce CO_2. The emission parameters for production of such a reusable reaction system was excluded from the calculation as only transportation and handling was considered as shown in Figure 2, however it is obvious that the structure itself is also a significant CO_2 emission source. Same is true for kentledge reaction system where the transportation costs and emissions are even higher.

Test Barrettes: O-Cell® bi-directional testing technology has enhanced the full-scale static load testing capabilities of barrettes worldwide. Not limited by load and shape among many other a rectangular section from 2.5 m to 7 m in length and ‘T’ shaped sections have been tested with mobilised loads of up to 220 MN as shown in Figure 5.

Figure 5. ‘T’ shaped barrette instrumented with Osterberg Cell.

Multi-Level testing: Loading can be made directly within the desired strata at any location within the pile or barrette shaft. Loading from the top of the element may require very high loads and internal stresses without actually mobilising the founding strata

Optimum design: We see the method of the test between top down and bi-directional testing has a factor of over 10 regarding the impact on the environment, however the overall footprint compared to the foundation works is still quite low as only approx. 1% of the piles are tested. Therefore, we should view the whole picture of the environmental impact of foundations and also focus on the technological advantages of bi-directional testing such as gaining more information about the pile behaviour such as separate skin friction and end bearing, pile movement and strain on different elevations, be able to static load test a certain soil layer with multi-level bi-directional testing. All these make a difference in design and implementing the gained information into a more economical final foundation design. These advantages triggering an even higher savings on CO_2 emission.

4.3 *CO2 emission trading market.*

CO_2 emissions according to the EU Emissions Trading System (EU ETS) are one of the most actively traded compliance markets. As countries and companies are given a limit on emission, they can buy extra allowance if they exceed their limit or allowed to sell unused allowances. This provides economic incentives for reducing emission.

Prices for CO_2 hover around 70-73 Euro/t as of mid 2025. Forecast suggests 91 Euro/t for 2026-2027, driven by tighter caps and EU border tax reforms. Over the last 10 years, the price for EU ETS has risen from approx. 10 euro driven by market reforms and increasingly ambitious climate targets.

Using these numbers bi-directional O-Cell is not just better for the environment but saves an additional thousands of Euros even for a small pile test. As soon as this becomes more sophisticated CO_2 emission will mean money gained or lost. EU aims to reach its net zero target by 2050 as part of their climate action plans and bi-directional testing has the potential to be able to contribute to this goal.

5 CONCLUSION

The bi-directional loading test has been a more economical, practical/functional and safer option over the traditional top-down loading method and considering the environmental effects on CO_2 emission shared in this paper it is also noted that the bi-directional testing is also a better environmental alternative, when compared with top-down method, either from using a loading beam plus anchor piles or a kentledge system. The additional instrumentation for bi-directional testing requires only 6% emission of what the top-down test requires in emission by virtue of the method making the bi-directional static load test save 94% of CO_2.

Considering that with higher loads the effort and emission for top-down test increases significantly, the relations above shifts even more in favour of bi-directional testing. 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, the bi-directional loading test is more advantageous as it will fulfil all new environmental requirements.

Concrete emissions will be many times as much for high load testing of larger foundation which include barrettes and larger diameter piles.

Extra construction materials, excavation works, transportation emissions and concrete for anchor piles for top-down load tests are avoidable producers of CO_2 emissions. We shall see more usage of smart pile engineering and testing for a more sustainable future.

6 ACKNOWLEDGEMENT

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