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State-of-the-art Report

The Cube system - a new diaphragm wall technique for future cities

Le système Cube - une nouvelle technique de paroi moulée pour les villes du futur

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ABSTRACT: Diaphragm wall technique is usually used to construct structural elements in the ground, commonly used for retaining systems, permanent foundation elements or deep ground-water barriers, named Cut-Off-Walls (COW). It can be anticipated that global urbanization and increasing demands on environmental considerations will need to be accommodated in underground space in the future. These trends show an increasing requirement for diaphragm walling in even more complex conditions, especially in inner-city applications with limited space. Therefore, there is the demand to minimize the size of equipment to accommodate such projects. Following this demand, a new trench cutter system, the so-called CUBE System, was recently developed. The complete trench cutter system has been fit into container size dimensions so that it can work in very limited space conditions. In addition, complex conditions in terms of space limitations require specifically adapted solutions for slurry, spoil, reinforcement and concrete handling and the related logistics to ensure smooth production. Due to the limited space requirements, the impact on the surrounding environment is limited. As the system is electric driven, an additional reduction of carbon footprint can be expected. First tests of the system have been carried out and the results will be shared. The paper will explain the construction process and the specific challenges and experiences made for these extreme conditions.

RÉSUMÉ: La technique de la paroi moulée est généralement utilisée pour construire des éléments structurels dans le sol. Elle est généralement dédiée à des systèmes de soutènement, des éléments de fondation permanents ou des barrières de retenue des eaux souterraines profondes appelées "cut-off walls" (COW). Les tendances et projections mondiales nous démontrent un besoin croissant en termes de demandes de projets de productions de parois moulées et ce dans des conditions encore plus complexes en particulier concernant les applications en zones urbaines aux espaces limités. En conséquence de quoi il existe une demande de réduction drastique de la taille des équipements dédiés afin de pouvoir réaliser les travaux. Afin de répondre à cette demande, un nouveau système de création de parois-moulées appelé « CUBE System » a été récemment mis au point. Le système complet a été adapté aux dimensions de containers afin de pouvoir travailler dans des espaces très limités. En outre, les conditions complexes en termes de limitation de l'espace nécessitent des solutions spécifiquement adaptées pour la manutention des boues, des déblais, des armatures, du béton ainsi que pour la logistique connexe afin de garantir une production sans heurts. En raison de cette demande de réduction d'espace, l'impact sur l'environnement est limité étant donné que le système fonctionne à l'électricité. Nous pouvons donc nous attendre à une réduction supplémentaire de l'empreinte carbone. Les premiers essais du système ont déjà été effectués et les résultats pourront être communiqués. L'article expliquera le processus de construction, les défis spécifiques ainsi que les retours d'expériences faits dans ces conditions extrêmes.

Keywords: Diaphragm wall; trench cutter; cube system.

1 INTRODUCTION

Urbanization trends showed an increasing population in recent years. Hand in hand the number of peoples living in cities is growing subsequently. To date, over 50% (around 4 billion people) of the world's population already lives in cities and urban areas. The expand of the cities calls for new infrastructure like new underground metro lines, water systems, logistic centres, underground parking and much more. This and rising prices in cities ask for solutions for future projects. Further, the demand for more resources and existing structures in the urban areas request technology, which can deal with great depths and challenging soil conditions.

Equipment suppliers facing challenges with competing trends of developing small equipment for inner city jobsites but also provide solutions for increasing depths. The challenge to develop machines with low emissions and solutions to reduce impact on daily lives sets restriction to fundamentally rethink methods and processes. In addition, the developments must be more and more powerful, to meet tight schedules and therefore are able to carry out cost effective projects.

One chance to confront these trends is the diaphragm wall method. It combines many features like the ability to be used in various soil and rock conditions with high performance or the possibility to use it in inner-city regions.

1.1 The history of diaphragm wall technique

Searching in the history of the diaphragm wall technique, one can find a first patent which was approved back in 1912 by a company called "Carl Brand" in Germany. This is based on the experiences for the use of clay slurries and it's stabilizing effect in uncased boreholes. Another patent was approved in the US by Ranney back in 1936. Both patents were almost forgotten before the method really started. A kind of revival and the real start could be seen in the late 1940's and early 1950's. Several publications discussed the thixotropic fluids and were patented by Hans Lorenz 1950/51. Also, Christian Veder received an Austrian Patent in 1950 for a methodology of installing water tide walls by using contiguous, uncased boreholes, stabilized by slurry and concreting after excavation. As well company "ICOS" applied for patents on slurry wall constructions by the end of 1940's in Italy. First full-scale projects have been finally carried out by ICOS for the Metro in Milan e.g., in 1956. With the success of the projects the interest in this technology increases. In addition, with expiring patents, several international construction companies, mainly in Europe and Japan, started to develop additional and alternative equipment for the purpose of installing Diaphragm walls (Gerressen, 2019).

1.2 Equipment history

1.2.1 The grab

To install the first rectangular diaphragm wall panels, ICOS designed a first special grab/clamshell, named crocodiles (Figure 1), which can be seen as the predecessor of today's grab/clamshell technology.

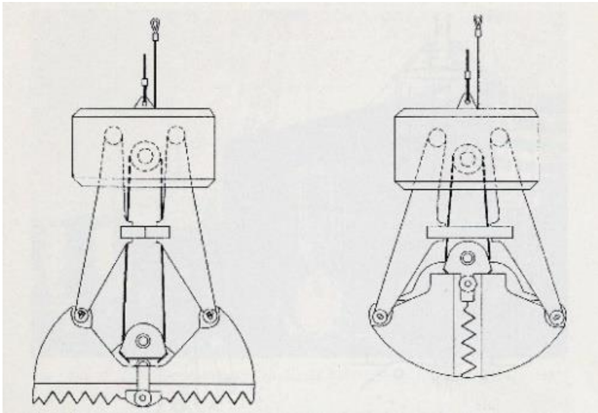

Figure 1. Wire rope grab (ICOS 1960).

A mechanically operated wire rope grab was used as the first type of excavating tool. The closing mechanism is actuated by a pulley block system inside the grab body, whilst the opening of the jaws is actuated by the weight of the block sliding on guides. The grabbing capacity of the initial generations of grabs was limited. The development of heavy-duty crawler cranes with two hydraulically operated winches made it possible to build grabs with jaw widths up to 4.5 m and a weight of over 15 tons. The excavation capacity of the grab system could therefore be increased significantly (Figure 2).

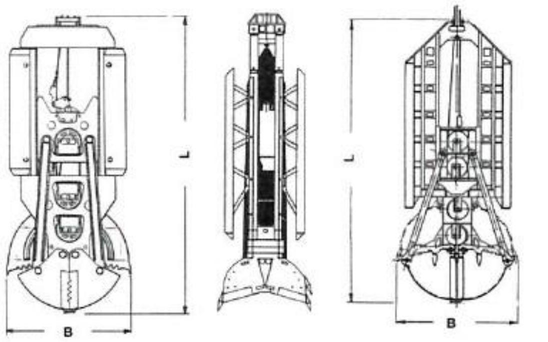

Figure 2. Wire rope grabs, Casagrande (left), Bauer (middle), Leffer (right).

Over recent years, the mechanically operated wire rope grab has been improved by replacing the pulley block system with hydraulically operated rams. Now, with both closing and opening of the jaws being actuated by hydraulic rams, the output capacity has increased significantly. Because of their heavy weight, these types of grabs do not need to be operated in a freefall mode. Hydraulic hoses and electric cables can, therefore, follow the grab into the trench without difficulty. The electric cables attached to the grab also allow the installation of inclinometers, and if necessary, deviations can be corrected by hydraulically operated steering plates as shown in Figure 3.

Figure 3. Hydraulic grab with steering plates.

The grab excavation technology is a widely used and common system. There are, however, some limitations in the system:

- The excavation output reduces with increasing trench depth because of the intermittent excavation process.
- It is difficult to excavate hard soil formations.
- For deep walls it is difficult to construct a sufficient joint system.

The introduction and development of the hydraulic trench cutter system made it possible to overcome these problems and it opened new horizons for the use of the diaphragm wall technique (Gerressen, 2019).

1.2.2 The cutter

In 1962, a kind of suction cutter unit was launched in Germany, which can be seen as one of the predecessors of today's cutter/hydro-fraise technology. Also, two Japanese companies (Tone Boring and Okumura Corporation) developed in the early 1960's a new reverse circulation concept for rectangular panels. While Tone Boring cutting blades rotated around vertical axes, Okumura used two cutting wheels, driven by a chain, and rotating around horizontal axes. The idea of a hydraulically driven cutter was introduced in Europe around 1975 by the French company Soletanche with the brand name "Hydrofraise". The arrival of the cutter technology in Europe prompted other companies to greater activities during the 1980's. Casagrande of Italy brought a system with a chain drive, like Okumura. In 1984 Bauer in Germany brought their system of trench cutter BC on the market. The BC system was designed from the beginning to penetrate rock layers. The cutter wheels are driven by vertically mounted high speed hydraulic motors. A special gear system converts the high-speed rotation of the hydraulic motors into slower rotation of the cutter wheels. With this system, the torque on the wheels can be increased in comparison to other design concepts. The torque of the cutter wheels combined with the weight of the cutter is strong enough to cut into hard soils, crush stones up to a certain grade and overcut into the concrete of adjacent panels. An overview of the various concept is shown in Figure 4.

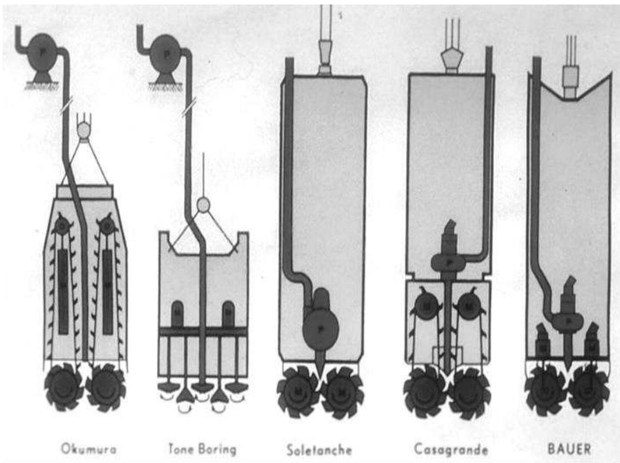

Figure 4. Cutter development.

The trench cutter itself is a reverse circulation excavation tool (Figure 5).

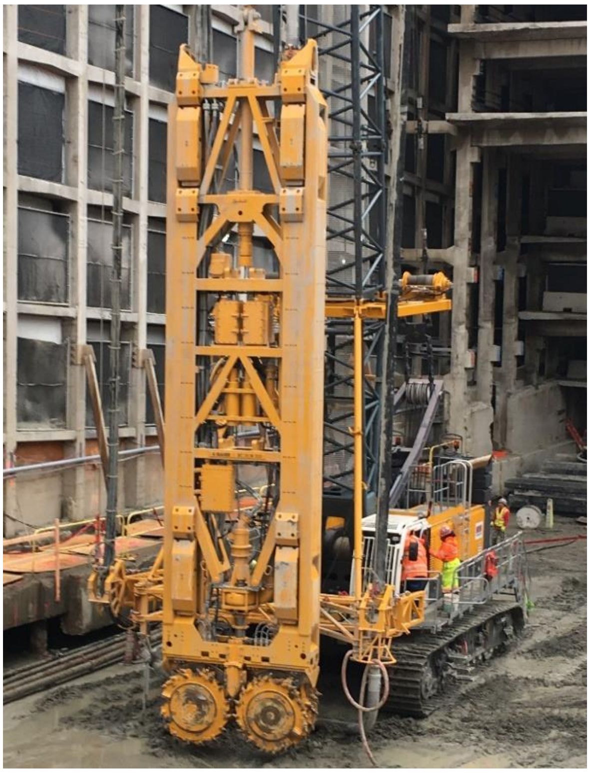

Figure 5. Trench Cutter.

It consists of a heavy steel frame with two drive gears attached to its bottom end, which rotates in opposite direction around the horizontal axis. Cutter wheels are mounted onto the drive gears.

As they rotate, the soil beneath the cutter wheels is continuously broken up, removed, mixed with the bentonite slurry in the trench and moved towards the opening of the suction box of the pump. A centrifugal pump located right above the cutter wheels conveys the slurry via a hose system up to a desanding plant.

Then the slurry loaded with soil and rock particles is cleaned and returned into the trench.

The torque of the cutter wheels combined with the weight of the cutter is strong enough to cut into hard soils, crush stones up to a certain grade and overcut into the concrete of adjacent panels.

Depending on the soil, different types of cutter wheel configurations and teeth can be deployed, ranging from aggressive teeth for cutting fine-grained soil to percussive teeth for crushing boulders. Cutter wheels may conveniently be changed to suit different types of rock.

2 WHERE WE ARE TODAY

2.1 Construction sequence

The working steps usually follow a pre-defined sequence. The main steps are shown in Figure 6. After a pre-excavation, which is necessary to allow starting the suction pump installed in the cutter frame, the excavation of a primary panel starts. Most common is to install multiple bite primaries as shown in Figure 6.

After finishing several primary panels, the installation of secondary, single bite panels takes place while overcutting the adjacent primary panels. The Overcut Joint System is a well proven way for the installation of diaphragm walls using the trench cutter system. In confined conditions the use of special auxiliary equipment (e.g., for installation of reinforcement cages) might become necessary. During excavation the open trench is stabilized by supporting fluid.

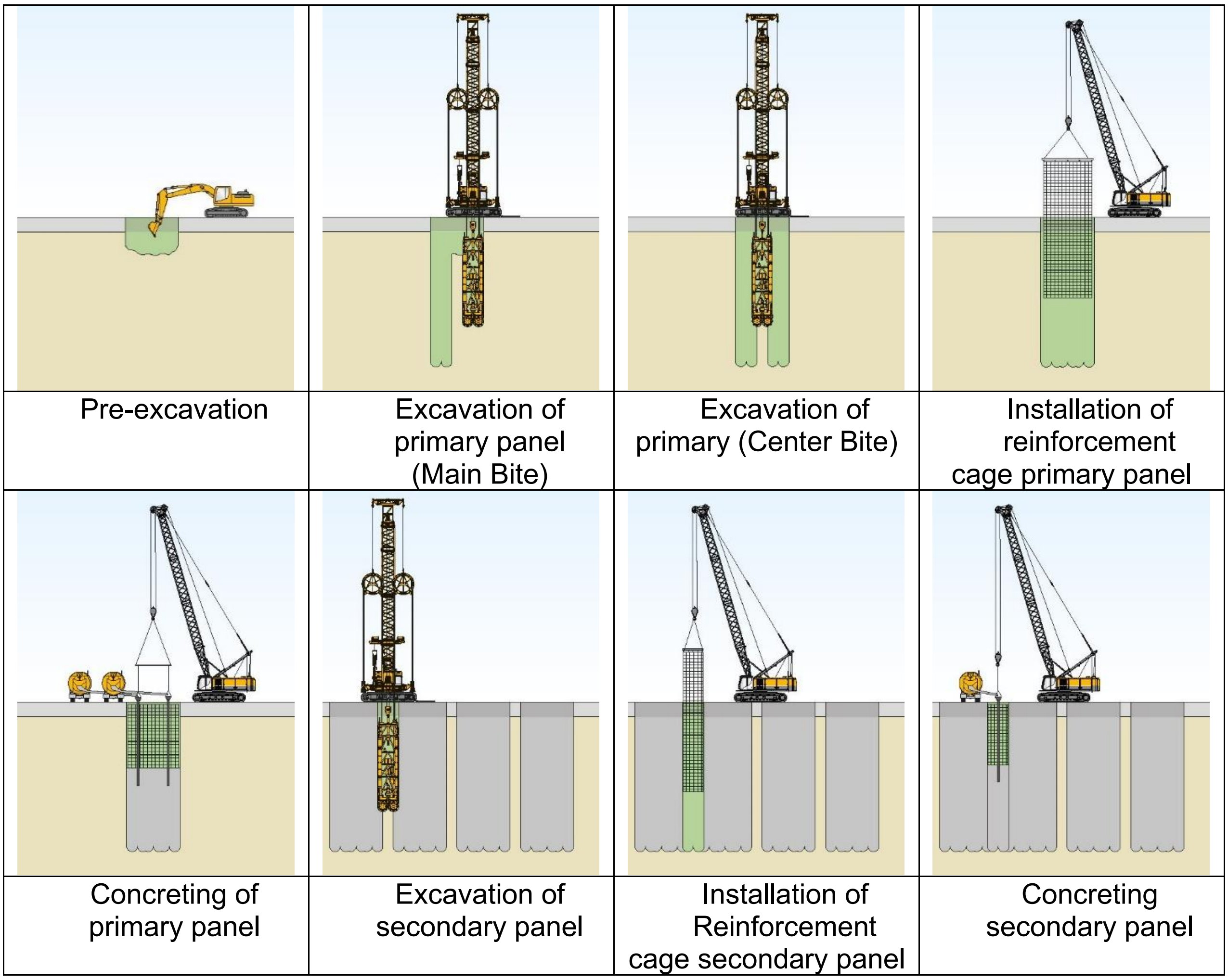

Figure 6. Construction sequence.

2.2 Site set-up and logistics

For diaphragm walling, the handling of the slurry is crucial and compared to other methods, a more complex site set-up becomes necessary.

Beside the cutter and its base carrier, other equipment such as desanding plant, mixing plant, different pumps and storage of the slurry requires space. Further access areas, for the supply of reinforcement cages, concrete and the transport of the excavated material are needed as well as storage of spare parts etc.

As the technique possesses many advantages, the demand to use it also in limited site conditions already led to a special carrier of reduced height, for so called low-headroom applications.

2.3 Development of equipment

Currently it is possible to monitor two different trends in the development of the equipment. On the one hand, it shall be possible to reach greater depth (Figure 7) and higher performance.

Figure 7. Cutter system for great depth up to 250 m.

On the other hand, small and confined situations require small flexible equipment (Figure 8) with low emissions (Gerressen and Blatt, 2020). Especially inner-city jobsites set challenges with the demand to new infrastructure. Over the years different contrary developments to satisfy demands took place. But all these developments had in common that it was possible to identify the diaphragm walling equipment. A completely new approach to widen the range of application is the so-called CUBE system, shown in Figure 9. The system is the next step in the miniaturization of the diaphragm wall technique.

Figure 8. Low-headroom cutter system.

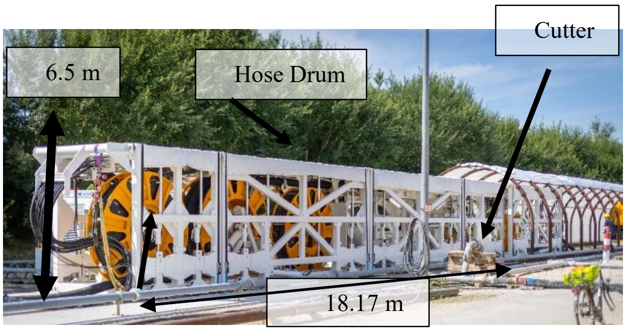

Figure 9. CUBE-System.

2.4 Aim of the system

The aim of the system is to provide additional possibilities. For example, it is possible to create walls out of underground structure, such as metro stations or tunnels. This new flexibility widens the range of possibilities during the planning stage of new infrastructure (for example underground car parking's, water reservoirs, storage areas, etc.). Currently new planned projects often cannot be planned and executed where it would be needed, as existing structures set restrictions. So, in some cases projects are not even started because of lack of technical solutions or enormous efforts in case of execution. In those cases, compromises must be made, e.g., find new not ideally locations, postpone or even cancel projects. With compromises always come additional costs over the lifetime of such a project.

Underground use of space is an important topic in that regard. If cities want to remain cultural, social, and economic centres, they will have to build as compactly as possible within the currently available space. The use of underground spaces as an extension of the urban public domain is an important part of this. But there is one major problem: much of the available space is already taken up by above-ground structures and traditional construction methods becomes increasingly difficult to justify. Now, in a

"Future City world Vision", the system allows planning of underground structures exactly where it is needed in conjunction with minimum impact on the environment above ground level. This creates new options and solutions for planers and urban development with an opportunity to explore the cities underground space better and safely. Due to its flexible application possibilities, great things can be created below ground, while life on the surface goes about its usual business. Execution of D-Wall out of a tunnel as shown in Figure 10 is one of the options. The depth of the tunnel is flexible and can be adjusted to the existing structures. To avoid additional works like e.g., groundwater lowering, it is recommended to have the tunnel above groundwater level.

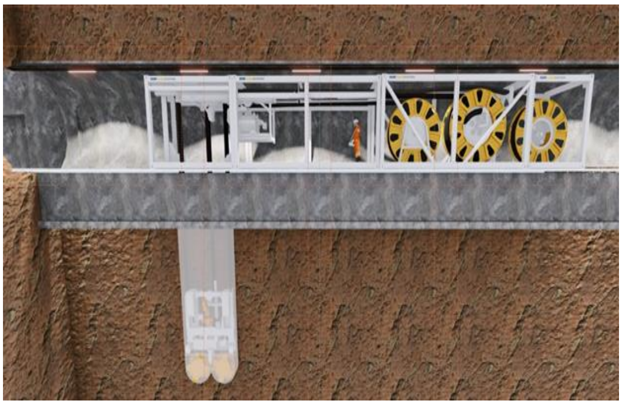

Figure 10. Cube system working in tunnel.

Figure 11. Cube system in very tight spaces.

An alternative of course is to use the system in very tight space conditions keeping e.g. the traffic alive, as shown in Figure 11.

3 THE CUBE SYSTEM

As the ones who have shaped the cutter technology in special foundation engineering, we thought it is time to redefine industry boundaries once again by the development of the BAUER Cube System. As the name indicates, the components are aligned in high cube container. The dimensions of the system can be seen in Figure 11. Within 4 high cube container it contains all known components of a diaphragm wall cutter. As displayed in Figure 12, panels with a length of 2400 mm and widths of up to 1000 mm are possible. To fit the cutter into the containers, it needs to be separated into two pieces. The first container accommodates the cutter head, where the cutter wheels and gearboxes are mounted. Within the second container the pumping unit is placed. To start the cutting process, this unit needs to be placed over the cutter head. For that a pre-excavation of only 1.5 m is necessary to lower the first part and therefore enable the second unit to move over. After both parts are connected, the cutter unit can work. The working principle is identical to standard trench cutting systems.

Because of the containerized dimensions, the need of heavy transports becomes irrelevant, which makes the system flexible and easy to transport. By connecting the containers with so-called quick ties, a fast and uncomplicated assembling can be ensured.

On both sides of the containers, passages make it possible to walk through (see Figure 12 at the right). This is an important factor to meet the safety standards for first aid access and material transport within a tunnel. Further it guarantees a safe environment for service tasks, such as teeth change on the wheels.

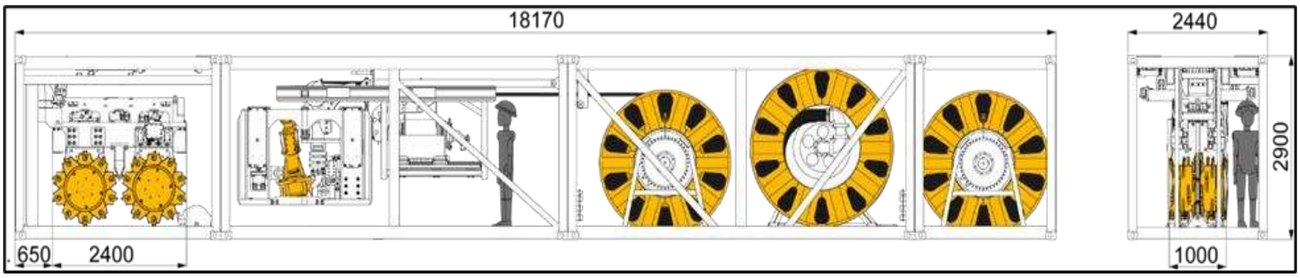

Figure 12. CUBE system - dimensions in mm.

3.1 Test site

In order to understand the processes and restrictions as well as to get a feeling for very confined conditions, a test was carried out first. Scope of the test was the construction of 7 single bite panels. Therefore, a complete jobsite set-up was assembled (Figure 13). In addition, a working platform, which included the rail system was constructed. Further a tunnel was simulated to work within height and width restrictions.

In total, five primary and two secondary panels were executed, whereby one primary was constructed to the maximum depth of 40 m. This is the actual maximum depth capability of the CUBE System. All other panels had a depth of 15 m. All panels were concreted using a concrete pump. Different reinforcement cages were tested. Further different equipment tests were carried out as well.

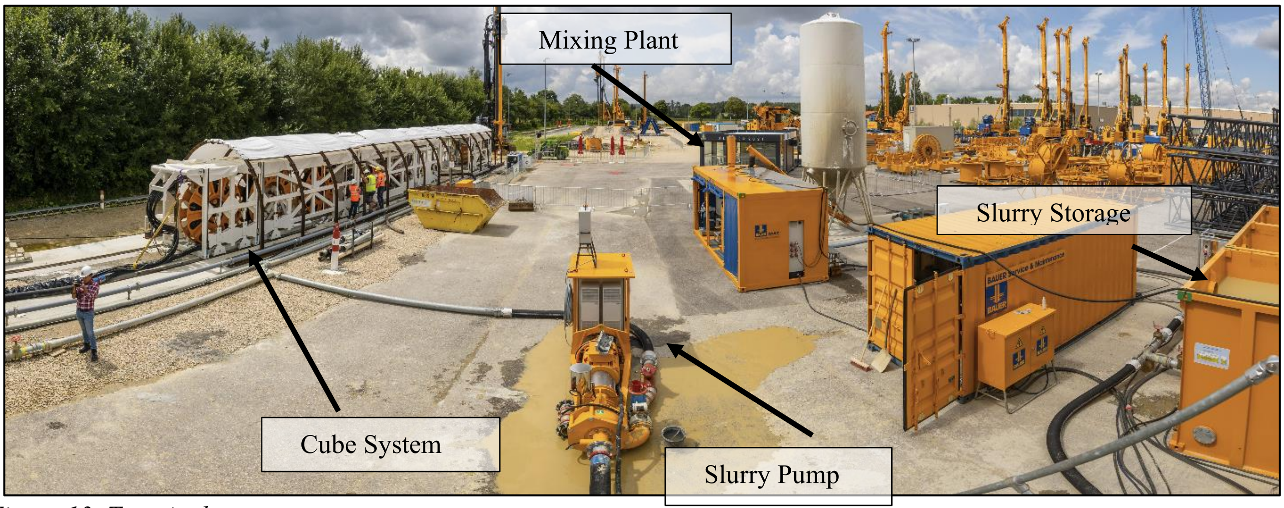

Figure 13. Test site layout.

As the cutter system is not mounted on a carrier with tracks, a new idea for the movement of the system was developed. The movement now is generated by a clamping device and by hydraulic cylinders, as shown in Figure 14. The device clamps hereby on a rail system and a cylinder push or pull the system in the desired direction. In the meantime, the opposite clamping device moves into position and ensures a continuous movement. Using this system, the CUBE system can move at a speed of 1.2 m/min.

Figure 14. Clamping device.

Like any other cutter system, a pre-excavation is required. The system can work with a reduced pre-excavation depth of 1.5 m, which can be carried out by a small excavator also within confined conditions.

The cutting process itself is not different compared to standard equipment. The loosened material is transported via the stabilizing fluid to a desanding plant. Here the solids are separated from the liquid medium, which is afterwards ready for reuse. Cutting performances on the test site were comparable with performances on sites with similar ground conditions.

Figure 15. Reinforcement and concreting container.

Although the cutting process is quite like the standard procedure, reinforcing and concreting are a bit more challenging due to the very limited height restrictions. Therefore, two different types of reinforcement cages were tested to assess the handling and installation during the construction within a tunnel. Each segment of the cages had a height of 1.85 m and were transported to an independent container. This container (Figure 15) contains all handling devices for the installation of the reinforcement cages and tremie pipes. Thus, it is also responsible for the concreting process.

During the test, it was found that the use of prefabricated cages in conjunction with the use of Lenton couplers as shown in Figure 16 was the most favourable solution for practical application. The connection time of two segments was approx. 15 min.

Figure 16. Cage coupling.

A concrete pump (Figure 17) supplied the concrete through the simulated tunnel to the trench (Gerressen et al, 2022).

Figure 17. Concrete supply via concrete pump.

4 CONCLUSION

With an increasing number of people moving into urban and inner-city areas, the demand for new infrastructure will also soar in the future. Existing buildings and structures as well as high prices for areal spread, set restrictions and for these new infrastructure facilities. In addition, environmental aspects will become more important and will raise the question for new strategies. The impact of these demands will further influence for the construction process and the design of equipment.

The importance to provide solutions for confined space jobsites with challenging soil conditions already rises difficulties for logistics, storage, and methods, as well as equipment to solve the restrictions. Today, suppliers already provide compact machines of high performance.

The CUBE System with its new design, new thinking of system and its reduced dimensions will make numerous projects possible, which lack of solutions until today.

The test proofed the functionality of the system and therefore provides opportunities for projects which had never been thought before.

With this, the system can become part of the "Future City world Vision".

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