Mixed-in-place techniques to improve dam safety and reduce seepage

Hans Schwarzweller[1], Jaime Sobrino[2], Mario Goulart[3]

1. *Regional Director, BAUER Fundaciones América Latina, S.A., Panama*
2. *Technical Manager, BAUER Fundaciones América Latina, S.A., Panama*
3. *Quality/HSE Manager, BAUER Fundaciones Panama, S.A., Panama*

ABSTRACT

Due to an increasing awareness, regarding dam safety and environmental concerns, related to seepage of contaminated fluids of tailings dams, tailor-made and cost-effective solutions to upgrade existing dams are becoming ever more important.

By mixing the existing soil strata of dikes or dams in-situ with binding agents – usually cement-bentonite slurry - using different techniques, improvements can be achieved in a fast and economic way with very little or no spoils.

The article will describe two different technical solutions – Mixed-in-Place (MIP) by augers and Cutter-Soil-Mixing (CSM) and gives examples of executed projects.

The Mixed-in-Place (MIP) method is ideal in non-cohesive soils and to depths up to 24 m approximately. In the MIP method, the surrounding soil is broken up with a single or triple auger, it is then mixed, and the pores filled in with the binder suspension. The individually treated areas are combined to form walls by the step back method. In this, it is the size of the auger(s), which ultimately dictates the dimensions of the newly formed cut-off-wall.

The Cutter-Soil-Mixing (CSM) method combines features of the diaphragm wall trench-cutter technique and the MIP method, as well as offering some additional benefits: the use of modified, high-performance cutters means soil mixing is possible even at greater depths and in densely packed soils. The method also enables even greater wall thicknesses and higher levels of reinforcement to be attained if required. Accordingly, in addition to the applications described for the MIP method, the CSM method is suitable in particular for reinforcing high dams and dikes. The main advantages and limitations of both methods are analyzed and quality control issues addressed.

In summary, soil-mixing solutions are highly attractive in economic and ecological terms and can be adapted to a great number of different site situations.

INTRODUCTION

Seepage control technologies such as cut-off walls are widely used in civil engineering, in dam and dike construction, for temporary and permanent groundwater barriers. Innovative construction methods and cut-off wall equipment have been developed over the last 40 years increasing application of soil mixing techniques for cut-off walls to a large variety of construction sites with vastly different constraints and subsurface conditions, for both civil and in mining projects. Cut-off walls are used as well to enclose contaminated areas or to direct contaminated ground water to a central water treatment facility.

METHODOLOGY

To minimize or even prevent disposal of excavated material during cut-off wall construction and to decrease the amount of slurry being used, active soil mixing systems are nowadays a state of the art technology. Best results in quality and performance can be achieved in uniform soil formations. The application is limited in heterogeneous soils with boulders, very compacted soils and rock formations. The Cutter Soil Mixing (CSM) system is technologically the most advanced system, using a modified trench cutter technique for constructing a cut-off wall. Deep Auger Mixing Systems are also frequently used but face various limitations compared to CSM. For each project, specific binder needs to be developed considering the in situ soil conditions and the required characteristics of the cut-off wall.

Mixed-in-place (MIP)

The term 'Mixed-In-Place' describes the process of mixing soil in-situ with binder. During this process, the pores within the soil structure are filled with the binder slurry. The result of this process is a strengthened body of soil in the shape of which is defined by the geometry of the augers (Figure 1):

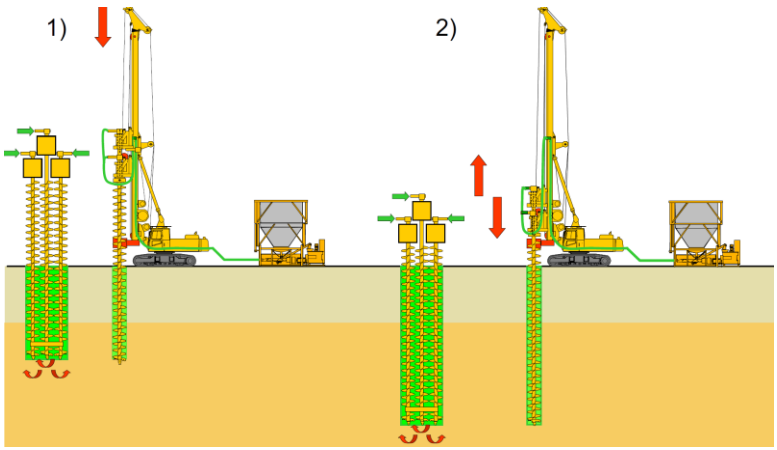

Figure 1: Mixed-In-Place (MIP) construction sequence.

Construction of a MIP trench is carried out by drilling a triple continuous flight auger to the required depth (Figure 2). During drilling and withdrawal of the augers, the soil structure is broken-up, thoroughly mixed and binder slurry is introduced through the hollow stems of the augers. In order to achieve complete homogenization of the soil during mixing, the rig operator is able to vary the direction of rotation for each individual auger and at the same time raise or lower the sledge mounted augers (Figure 3). Construction of the MIP panels is carried out in bites (Figure 4) by adopting the so-called 'back-step' construction sequence. Thus ensuring a continuous wall without joints. If required, project specific reinforcement can be installed by lowering it into the freshly mixed wall.

Figure 2: Mixed-In-Place equipment.

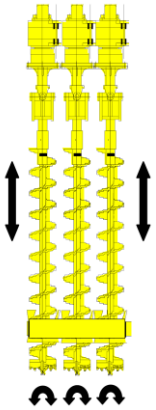

Figure 3: Movement options during mixing.

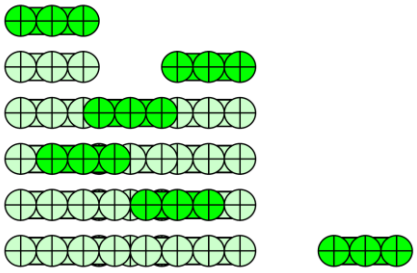

Figure 4: 'Back-step' construction sequence.

Cutter Soil Mixing (CSM)

The two counter rotating CSM cutter wheels penetrate into the ground at a continuous rate. The cutting wheels break up the soil matrix and at the same time, a fluid is pumped to the nozzles set between the cutting wheels, where it is mixed thoroughly with the loosened soil. Adding compressed air stream can improve the breaking and mixing process during the downward movement of the cutter. The rotating cutter wheels push the soil particles through vertically mounted shear plates thus completely mixing the materials. The penetration speed of the cutter and the volume of fluid pumped

in are adjusted by the operator to create a homogeneous, plastic soil mass, which permits easy penetration and extraction of the machine (Figure 5):

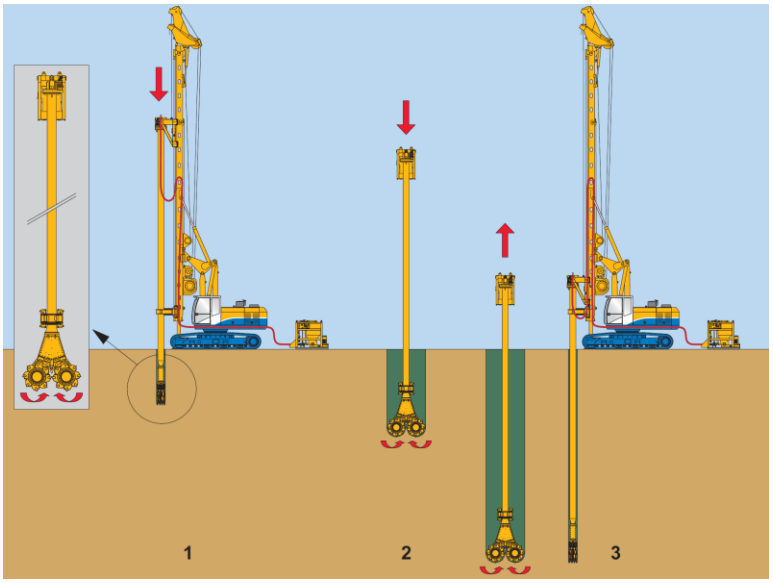

Figure 5: Cutter Soil Mixing (CSM) construction sequence.

Having reached the design depth, the soil-mixing cutter (Figure 6) is slowly extracted while cement slurry or cement-bentonite continuously added. The mixing and withdrawal speed in combination with the required binder-slurry volume is carefully planned and controlled. Homogenization of the liquefied soil mixture is ensured by the rotation of the cutter wheels. A continuous wall is formed in a series of overlapping primary and secondary panels. Overcutting into fresh adjacent panels is called «fresh-in fresh method», but also the «hard-in-hard method» is possible, whereby the panel is cut into already hardened primary panels. Installation of reinforcement into fresh panels is possible as well.

Figure 6: Kelly-guided CSM and rope suspended Tandem Side Cutter on MT 75.

QUALITY CONTROL

An extensive testing program according to a Quality Management Plan shall be undertaken to monitor and control the complete production process and to check the final product. This includes all steps of the entire process like preliminary preparations, site set-up, materials delivery, slurry production, storage and transport, and in-situ mixing thus ensuring the quality of every single panel and the envisaged wall-continuity. In general, samples are taking of every delivery of cement and bentonite and tests for the slurry density, Marsh time and temperature are done in the usual way directly after mixing. In addition, the slurry volume is measured with a flow meter and recorded with electronic devices (B-Tronic). Slurry samples are taking during each shift to control the curing process of the slurry. The homogenization of the in-situ mixed materials has to be verified by sampling directly from the wall immediately after the mixing process has been completed. The final product can be checked by conventional core taking.

RESULTS AND DISCUSSION

MIP or CSM cut-off walls have limited structural function. To improve the stability of the dams or dikes, individual soil-mixing-elements can be reinforced by steel-elements. In addition further soil-mixing-elements orthogonal to the barrier wall can be installed. Number and lengths of such stabilizing elements depend on the project's requirements and the prevailing soil. With the techniques described soil permeability less than 1 x 10^{-8} m/s can be achieved minimizing seepage, improving the overall long-term dam stability. Compared to other cut-off wall solutions soil-mixing techniques are both economical and fast solutions with only limited volume of material transported to and from site. No concrete is placed as the in-situ soil and binder-slurry is used as a construction material and limited drill spoil is generated. Other existing barrier systems, for example those constructed with conventional grouting methods, often fail to meet the degree of efficiency and durability and other performance specifications over the life of the structure as required by the design. Both soil-mixing techniques use relatively light equipment when compared to conventional dig and replace techniques like grabs and cutters.

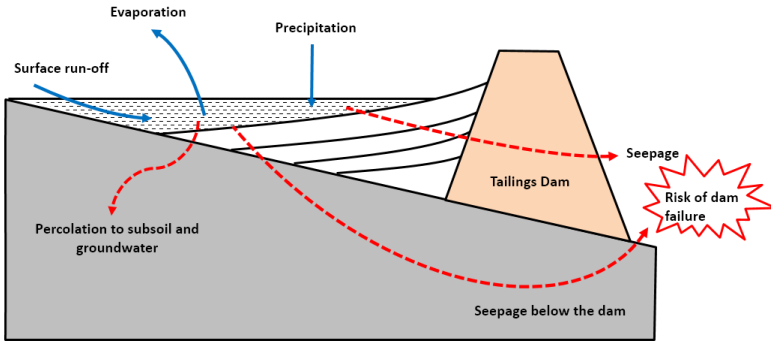

Figure 7a: Existing tailings dam with seepage problems.

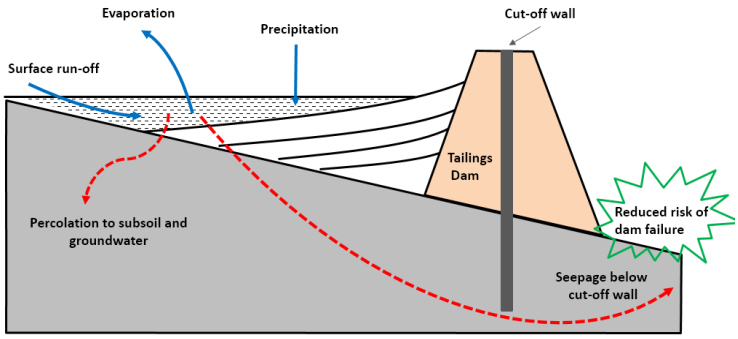

Figure 7b: Rehabilitation of existing dam by installation of cut-off wall.

Depending on the depth of the installed cut-off wall, the level of the downstream water table can be influenced. In addition, the reduced seepage of eventually contaminated tailings liquids will improve the ground water quality in the areas downward the dam.

Case studies:

1. Cutter-Soil-Mixing Wall at Fort McMurray, Alberta, Canada:

The project was governed by two main factors: schedule and temperature. The specialist foundation-engineering contractor had been approached to execute a cut-off wall that was approximately 900 m long and up to 13 m deep at the South West Sand Storage (SWSS) at the Syncrude site. The main criteria were the execution during severe winter conditions, as the Fort McMurray region is known for its cold conditions from November to March. The construction of the wall in these winter conditions created many unique problems with handling equipment and materials that specialist foundation-engineering contractor had to solve. A common soil-bentonite wall was not possible due to the freezing of the slurry in the open trench. Frost would also prevent the mixing of the excavated material with the slurry and bentonite powder to create the homogenous soil bentonite mixture as usually used. The solution for this project was a Cutter-Soil-Mixing (CSM) wall. The Bauer CSM-method allows the bentonite-cement-binder-slurry to be injected directly into the soil at the location of the treated wall. Only the first 0.5 m to 1 m of frozen soil had to be removed to create a small trench to contain any overflowing suspension. The specialist foundation-engineering contractor's solution for handling the slurry preparation equipment was to set up the mix plant inside a large heated tent. To guarantee that the slurry would not freeze while being pumped from the tent through a heated booster station on to the machine up to 500 m away, the slurry line had heated connections and insulation wrapping the line. The soil mixing was performed by a BAUER RTG 19 with a BCM 10 cutter attachment. To speed up the production process of the cutter pre-drilling was performed by a BG 18 drill rig and a continuous auger. This enabled the contractor to treat the sandy soils and to finish the project on time allowing the client to continue operations without any impact on the production.

Figure 8: Cutter Soil Mixing equipment.

2. Mixed-in-Place (MIP) Wall at Sonthofen, Germany:

After floods in 1999 caused extensive damage along the River Iller in southern Germany (Figure 9), the embankments were post sealed by vertical cut-off walls constructed by the triple-auger Mixed-in-Place method with steel elements installed as reinforcement. During the floods of August 2005, the embankments were subjected to a severe test earlier than anticipated. The result: the MIP-stabilized and reinforced embankments withstood the lateral pressures caused by the extremely high water table of the river as designed even when being overtopped.

Figure 9: Mixed-in-place triple-auger technique. The MIP – wall, while being overtopped prevents levee to collapse during flood event.

CONCLUSION

The article demonstrates that Mixed-In-Place (MIP) and Cutter Soil Mixing (CSM) are suitable methods to install cut-off walls within existing dams and dikes in a fast and economical way. The design can be adapted to a great number of different site conditions according to the requirements of the project. Whilst cut-off walls executed in conventional ways similar to diaphragm walls have been used for the rehabilitation of tailings dams the authors are not aware of the execution of mixed-in-

place cut-off walls in this field. In consideration of the benefits mentioned in this article the techniques mentioned here could become of interest for a number of tailings rehabilitation projects in future.

NOMENCLATURE

CSM	Cutter soil mixing
MIP	Mixed in place

REFERENCES

Arnold, M., Beckhaus, K., Wiedenmann, U. (2011), 'Cut-off wall construction using Cutter Soil Mixing: a case study', *Geotechnik 34 (2011), Heft 1.*

Banzhaf, P., Colmorgen, B. (2011) ´Reliable seepage control by plastic concrete cut-off walls´, *USSD 21st Century Dam Design – Advances and adaptations, 31st Annual USSD conference, San Diego, CA, USA.*

Bauer Maschinen GmbH (2016) 'CSM Cutter Soil Mixing, Process and Equipment', *Schrobenhausen, Germany*.

Bauer Maschinen GmbH (2016) 'Mixed-In-Place', *Schrobenhausen, Germany*.

Banzhaf, P. (2016) ´Dam Safety for new and aging dams – seepage control using advanced construction techniques – tailor-made to meet the individual project and owner's needs', *Schrobenhausen, Germany*.

Stefan, S. (2016) 'Cut-off Wall Technologies in Mining', *Proceedings IMWA 2016, Freiberg, Germany*.