DEEP FOUNDATION INSTITUTE®

DFI

Proceedings of Conference on

Deep Foundation Technologies for Infrastructure Development in India

(with Souvenir & Exhibitors Catalog)

September 19-20, 2014

INDIAN GEOTECHNICAL SOCIETY
DELHI CHAPTER

Department of Civil Engineering
INDIAN INSTITUTE OF TECHNOLOGY DELHI
Hauz Khas, New Delhi - 110016

SUSTAINABLE FOUNDATION ENGINEERING – MIXED-IN-PLACE TECHNIQUES FOR DURABLE CUT-OFF WALLS

Peter, Banzhaf

BAUER Spezialtiefbau GmbH, Schrobenhausen, Germany, +49 8252 974266, +49 8252 971496, peter.banzhaf@bauer.de

Abstract

Sustainability in construction means, among other aspects, the limited use of construction material, the reduced number of construction equipment, the minimized number of transports and overall decreased use of energy, therefore reduced cost without compromising on quality.

Due to the long history of Mixed-in-Place (MIP) in foundation engineering, these techniques with remarkable developments in the way of execution and the equipment used have turned into an internationally accepted method to install durable permanent MIP-cut-off walls even in levees and embankment dams.

Historical MIP-auger techniques have been advanced to mix and homogenize soils ranging from gravels and sands to silt with some parts of clay – important is the slurry mix used and the mixing technique as such. The MIP-auger technique is lately supplemented by the MIP-cutter technique. Key advantages are cutting and mixing into soft rock, penetrating and mixing limited rock layers and reaching depths not attainable with the auger technique.

1. INTRODUCTION

1.1 History and Utilization

Mixed-in-Place (MIP) techniques to form vertical elements in appropriate soils are in-situ deep mixing construction methodologies known since more than 50 years. They will be distinguished between dry and wet methods and for the wet method between different ways of mixing to achieve the designed improved soil property.
Porbaha et al (2005) categorized deep mixing application into six main applications, namely:

- Hydraulic barrier systems
- Retaining wall systems
- Foundation support systems
- Excavation support systems
- Liquefaction/Seismic mitigation systems
- Environmental remediation systems

1.2 Techniques provided

For forming vertical elements in the ground to install seepage barriers or structural elements primarily the wet mixing methods are being used. Methods applied are:

- Single auger mixing method
- Triple auger mixing method
- Multiple auger mixing method
- Cutter soil mixing method
- Trench cutting Re-mixing deep method (TRD)
- FMI (Misch-Injektionsverfahren) trenching machine method

In particular, the triple auger mixing method – the MIP-TAT – has successfully been used by Bauer since beginning of the 90ties of the last century. This technique proved to be

ideal to reach depths to 25 m and to homogenize different types of soils including small cobbles with the binder slurry. The binder is introduced at the tip of the middle auger proving to be ideal for uniform distribution of the slurry into the entire mixing area.
The technique of reversible augers together with the back-step sequencing of panel installation demonstrated to produce continuous, uniform seepage barriers and construction pit walls. The tested permeability of MIP walls successfully reached $\leq 10^{08}$ m/s after 56 days. Strengths achieved after 56 days range between 1.5 and 3 N/mm² as shown in Figure 1.

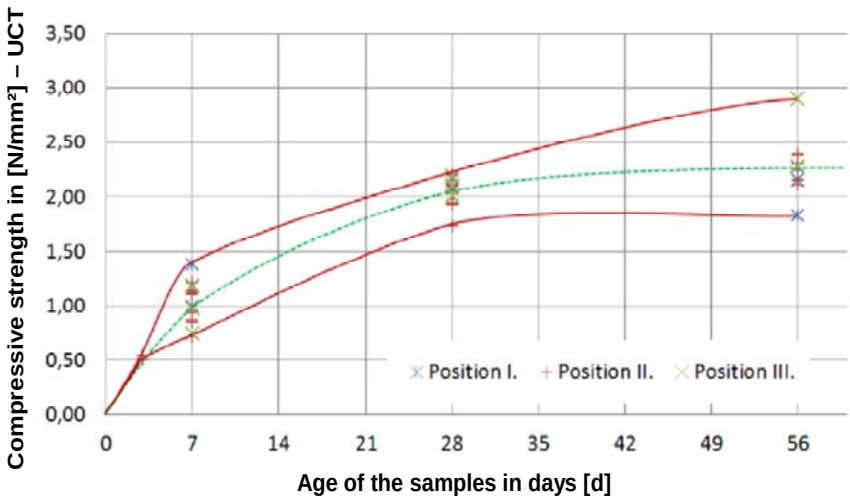

Figure 1. Compressive strength reached of MIP-TAT samples after 56 days of curing (BST).

The Cutter soil mixing method – MIP-CSM – supplements the MIP-TAT by reaching depths of more than 45 m with the Monokelly configuration. Very specialist machines reach rope-suspended up to 60 m. Furthermore, the cutter technique is able to penetrate limited rock layers and is designed for embedment of the MIP-panels into rock.
In this paper the main focus is on the economical MIP triple auger mixing method – the MIP-TAT achieving high performance rates in granular-silty-clayey soils.

Photo 1. BAUER BG40 rig with MIP-triple auger technique (MIP-TAT) set-up (BST).

1.3 Materials used

Soil stabilization involves the use of stabilizing agents (binder materials) in weak soils to improve its geotechnical properties such as compressibility, strength, permeability and durability. Different cementitious materials are being used to prepare the slurry being mixed with the soils resulting in a type of earth-concrete. Binding or stabilizing agents like cement, pozzolan, slag or lime are used in different proportions depending on design requirements and the soils being mixed. Additives support the mix-design to adapt to site

requirements. Organic matters and sulphate in the actual soils and prevailing climatic conditions for the specific project have to be considered in the design phase to achieve a long-term improved soil-binder mass.

2. THE MIP-TRIPLE AUGER TECHNIQUE (MIP-TAT)

2.1 The advantages of this economic technique

Work sequence: To ensure that a solid, continuous wall is produced, MIP walls are constructed by the double-pilgrim-step or back-step method. This production sequence is characterized by additional working of the overlap zones comprising primary and secondary cuts. Thus the triple auger penetrates and mixes each wall element at least two times ensuring the overall homogeneity and continuity. Table 1 presents the MIP-TAT wall production sequence.

Table 1. MIP-TAT wall production sequence.

"Double-pilgrim or back-step" production sequence

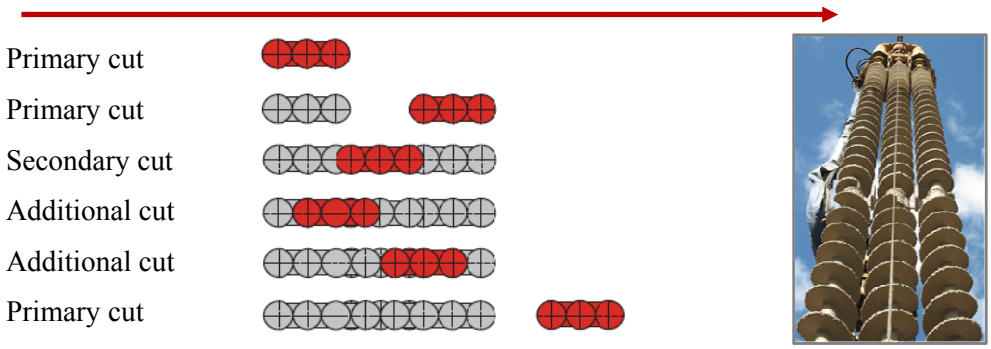

Photo 2. MIP-triple auger.

2.2 Design aspects

Historically MIP elements are being used as cut-off elements without structural function and had been executed unreinforced. With increase in quality assurance due to improved equipment, improved slurry mixes adapted to individual soils and more experience in the execution of MIP elements, structural walls had been designed and successfully executed. Structural walls for excavation pits are regularly reinforced with H-beams and, for higher lateral loads due to greater depths, tied back with anchors. For such design approach BAUER Spezialtiefbau GmbH obtained the Technical Approval Z-34.26-200. Figure 2 shows the design concept of a MIP-TAT wall reinforced with H-beams and tie-back anchors.

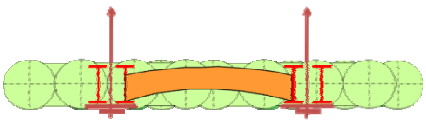

Figure 3. Design concept of a MIP-TAT wall reinforced with H-beams and tie-back anchors.

Lateral loads like earth pressure and loads from traffic or ancillary equipment are being transferred by arching effect to the H-beams and hence to the tie-back anchors. The wall thickness is defined by the diameter of the augers – a typical diameter is 55 cm.
For hydro structures like levees both cases – unreinforced as cut-off or reinforced with H-beams as cut-off with structural use are being built.

2.3 Equipment used

The lead equipment is a crawler mounted base machine with hydraulic driven mixing augers – for typical MIP-rigs see Photo 1 and Photo 3. Some surplus materials (soils with some slurry) are loaded by a backhoe or shovel loader and cart away by a sufficient truck.

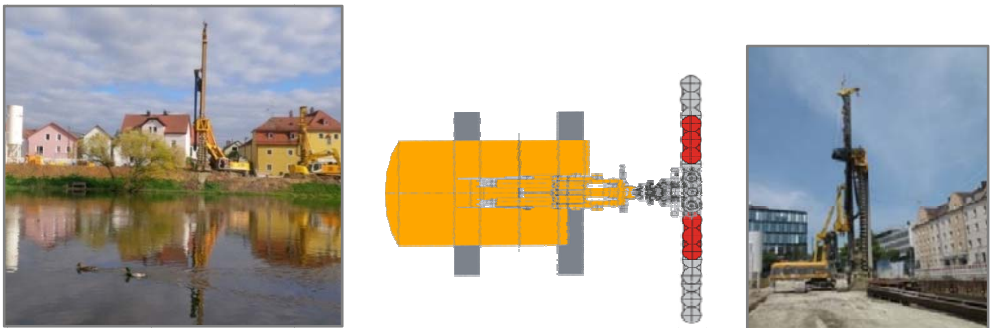

Photo 3. BAUER RG25 base rig with MIP-TAT configuration (BAUER Spezialtiefbau GmbH).

For operation of the MIP system, auxiliary equipment is required. Silos for the material to be composed to the project specific slurry, mixing units, agitator units and the feeder pump are required to mix and transport the slurry to the MIP-rig.

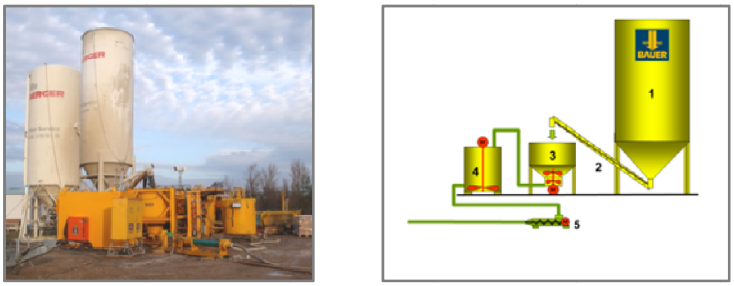

Photo 4. Auxiliary equipment – Typical setup of a slurry mixing plant for the MIP method (BAUER Spezialtiefbau GmbH).

Legend: 1 Silo(s); 2 Conveyor augers; 3 Mixer units; 4 Agitator units; 5 Mohno feeder pump

2.4 Binder material

For the deep stabilization of various soft soils like clay, peat as well as loose to very loose granular soilsdifferent types of binders can be applied. However, the geotechnical and chemical properties of the soil to be stabilized will affect the results of stabilization and the choice of the appropriate binders. For the installation by a “wet method” 2-component binder mixes are widely used but 3-component binders are more versatile and can bemore effective in many cases. The most important components **for the “wet method” are cements, blast furnace slag, limes/limestone filler and powdered clay**. High quality fly ashes can be exploited for certain cases (EuroSoilStab, 2002).
Installation of the well-designed project specific binder slurry by a proven method and experienced contractor will result in a higher strength, lower permeability and lower compressibility of the original soils.

2.5 Quality control

Quality assurance and control are essential to the success of the MIP methods. Prior to execution for preliminary suitability tests, the binding agent suspensionmix and the

optimum quantity of it are being determined on the basis of soil and groundwater samples taken from the site.

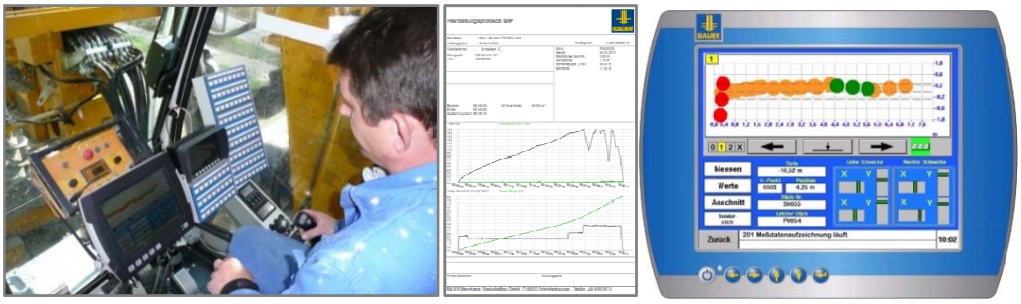

Photo 5. The experienced MIP-rig operator controls performance data incl. verticality and overlap of the individual elements ensuring a continuous wall. Reports are provided (BST).

During execution, the key production parameters, such as suspension flow rate and volume installed, auger speed and penetration depth, are continuously monitored, recorded by a data acquisition program and documented as required. Reference samples are taken in regular intervals from the fresh trench.

2.6 Economic and ecological aspects

A comparison of transport volumes between the construction of a MIP wall and a pile wall very clearly demonstrates the economic and ecological benefits. In comparison with other stabilization methods the main advantages of deep stabilization are: - economic / - flexibility / - savings of materials and energy / - rapidity / - can be flexibly linked with other structures and with the surroundings (no harmful settlement differences) / - flexible improved engineering properties of the soil (EuroSoilStab, 2002).

	Spoil removal from the site	**Building materials concrete, cement, bentonite to the site**

MIP-TAT wall

Secant bored pile wall

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2.7 Applications of the method

MIP-TAT elements are used to form temporarily used and permanently used constructions for different applications.MIP walls are being designed as cut-off walls for sealing purposes and as structural walls for excavation pits or as foundation elements for foundations.

2.7.1 Structural walls for excavation pits – temporary or permanent

Excavation support systems are typically installed as structural walls with H-beams and tie-back anchors. After or during excavation of the construction pit, the walls are vertically smoothed by road-header equipment or similar to allow for using as shutter.

Photo 6. MIP-TAT – structural retaining wall with tie-back anchors (BST).

2.7.2 Hydraulic barrier systems – Permanent cut-off walls – unreinforced or reinforced

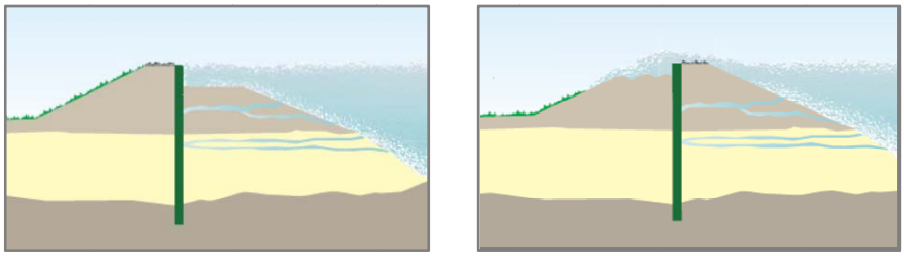

Figure 4. Adequately installed reinforced MIP walls resist riverside erosion and even overtopping (BST).

Levee or dam cut-off walls are installed with MIP-TAT method wet-mixing a designed slurry with the embankment materials. This system is successfully used to remediate and strengthen such hydro structures.

2.7.3 Retaining wall systems – Combined cut-off wall and foundation element

Retaining walls or excavation pit walls (see Photo 3 and Photo 6) are installed for temporary or permanent purpose. The low-vibration works means that less strain will affect the existing structures nearby.

2.7.4 Environmental remediation systems – Immobilization

MIP columns arranged tangent to each other or overlapping are the method to be selected for immobilization of local contaminations in the soils in accordance to local law. Contaminated soil particles are restrained against being washed away by groundwater.

2.7.5 Foundation support systems – Soil improvement

MIP elements are being designed and installed either as foundation improvement under building slabs or as singular foundation elements under columns. Similarly MIP elements are being installed as Liquefaction/Seismic mitigation systems.

3. CONCLUSION

With the MIP-TAT (Triple auger technique) a deep mixing method is chosen to install vertical elements as seepage barriers and/or structural walls in an economical an environmental friendly way. The MIP-TAT elements can be reinforced to improve their structural function. Seepage barriers for levees are common practice since more than 30 years. The elements are designed project oriented, considering the prevailing soils and climatic conditions. Furthermore, the system is being selected to form permanent cut-off walls in embankment dams due to its reliability.

Photo 7. A levee at the river Iller in Germany overtopped during the 2005 floods – still the installed MIP-TAT wall stayed in place and prevented the complete discharge of the river (BST).

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