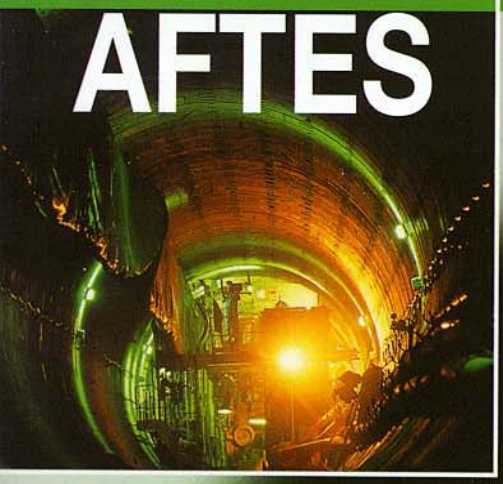
Association Française des Travaux en Souterrain

AFTES



JOURNÉES D'ÉTUDES INTERNATIONALES DE TOULOUSE

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LES SOUTERRAINS : DES OUVRAGES QUI VIVENT

UNDERGROUND WORKS: LIVING STRUCTURES

LAS OBRAS SUBTERRÁNEAS : OBRAS VIVAS

SOIL CONDITIONING FOR TBM
CHANCES & LIMITS

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ABSTRACT: The TBM method becomes increasingly common in the tunnelling world. However, the success of a TBM drive not only depends on good technical and human resources but also on well chosen soil conditioning additives. In order to reach maximum efficiency during tunnelling, it is useful and necessary that the latest developments concerning TBM-additives are well known. Big steps forward have been made regarding difficult geology like sticky clay or clayey soils as well as regarding porous and coarse soils.

RÉSUMÉ: Dans le monde du tunneling, l'utilisation des machines TBM est devenu de plus en plus fréquent. Le succès, par contre, ne dépend pas uniquement d'une bonne machine et d'une bonne équipe – mais il est aussi fortement dépendant des additifs de forage. Afin d'attendre un maximum d'efficacité il est donc indispensable de connaître les capacités actuelles des additifs. En particulier dans des sols argileux ainsi que dans les sables graviers beaucoup de nouveautés ont été développes et utilisés.

1 - WHICH TBM-TYPE SHOULD BE USED?

One of the most difficult questions during the tender stage is: Which type of TBM is the best for the given geology? In the case of hard rock geology the only machine possible is a hard rock machine, but in soft ground conditions the big question still remains:
Is it better to use EPB or Slurry mode?
Two important factors to answer this question are

- the existing know-how of a construction company due to their job references and human skill-level
- the capability to incorporate new technologies which change the original working method.

In consequence, it is extremely important to be fully aware of the new technology and its possibilities.

Conventional TBM placement

A good example of the state of the art regarding the above mentioned question is given by C. Becker [1] including interesting case studies.
Following the actual literature, the generally existing split of Slurry and EPB technology is more or less expressed in figure 1.

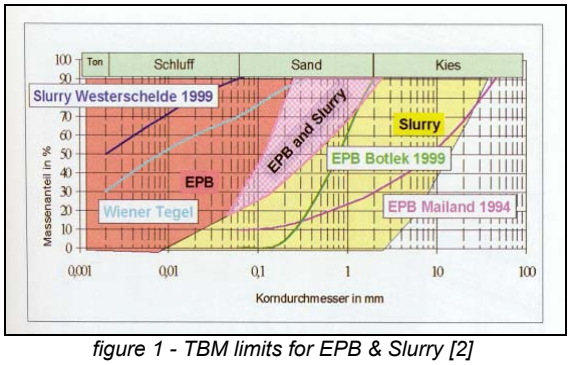

figure 1 - TBM limits for EPB & Slurry [2]

The operation areas of EPM and Slurry-Machines are generally separate. Therefore, a conflict of whether to use EPB or Slurry technique should be rare. But already the given examples of Botlek and Milano indicate, that the capacity of the EPB technology is much broader than frequently used.
The advantages of EPB machines have mainly been listed by C. Becker [1]: the most important argument is that the soil itself is not drastically changed - only temporarily by Foam & Polymer - and therefore no costly secondary treatment like Bentonite separation is necessary. However, the indicated limiting parameters for EPB drives have been changed due to the existence of new conditioning additives.

Extension of EPB technique

The range in use of both EPB and Slurry machines are indicated in figure 1. This range is far greater today due to new soil conditioning additives. Concerning clayey soil, they can reduce adhesion and stickiness, in coarse soil they widen up the range of use for EPB shields towards a highly porous geology.
This possible extension is very important for the cost calculation of a project, because of the following reasons:

- EPB technique needs no separation plant
- EPB technique is also possible in inhomogeneous soils.
- well conditioned soil allows excellent pressure control and limits settlements
- EPB is possible in contaminated ground, where only the excavated quantity has to be treated afterwards
- soil conditioning additives may reduce the necessary cutterhead torque drastically, in consequence large tunnel diameters are possible.

Some of the listed limits of EPB technology [1] are no longer valid, thanks to new generation of soil conditioning additives.
Some characteristics are described in the following chapters.

2 - NEW SOIL CONDITIONING ADDITIVES

The development of new soil conditioning additives covers two main areas:

- Clayey soils:
  reduce sticking & adhesion effects
- Sandy gravel soils:
  reduce permeability and increase soil stability

2.1 Clay additives

If a TBM works in clayey soils, in most cases problems occur due to their stickiness & adhesiveness. This results in low advance speed of the TBM and huge maintenance - both representing high cost factors.
In order to decrease the stickiness & adhesiveness, Foam can be used if the clay content is not too high. In this case the links between the clay particles are broken down by the functional group of special types of tunnelfoam (surfactant). In figure 2 this group is shown by the red ellipse.
If the clay soil causes stickiness problems on the TBM even when using foam, the links between the clay particles are stronger than the functional groups of the foam. In this case only the use of clay dispersants may help. Clay dispersants have multiple and very strong functional groups (highlighted in red) per molecule, their capacity to break down the links between the clay particles is in consequence much higher than those of foam.

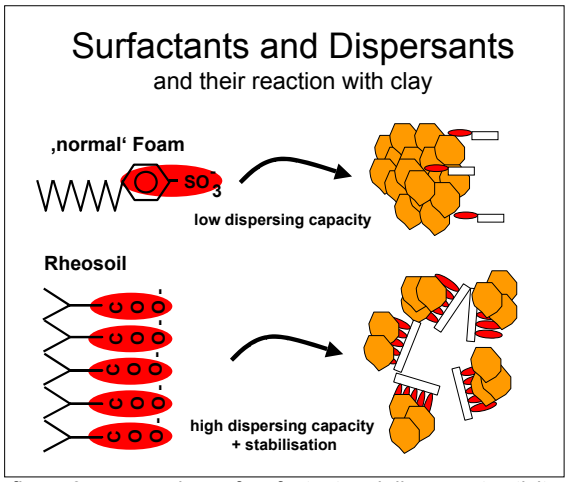

figure 2 – comparison of surfactant and dispersant activity

However, not all dispersants which may show an effect together with the soil are useful in the TBM technology, because these additives have to be compatible to the used Foam and also have to represent good toxicological and ecotoxicological data.

2.2 Soil structuring additives

If a TBM works in porous soils (M>10^{-4} m/s), in most cases problems occur due to incoming water or impossible pressure build-up.
In this situation it is necessary to create cohesion between the soil particles and to avoid segregation. In order to obtain these characteristics, it is necessary to use a combination of Foam and a structuring Polymer – in most cases this will be a long chain Polymer as described in figure 3.

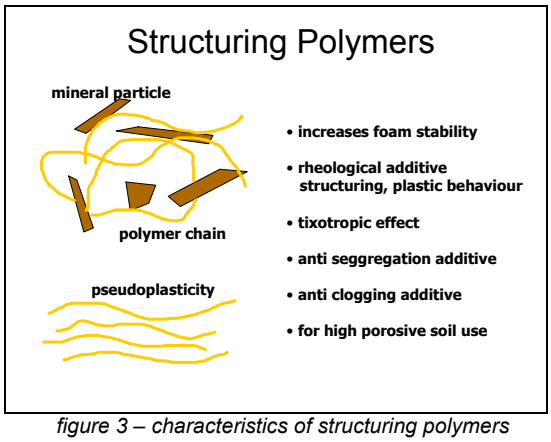

figure 3 – characteristics of structuring polymers

In the special case that the tunnel is above the ground water level, it might also be possible to use a combination of Foam and short chain polymer (for foam strengthening).
In the case of very porous soil it might be useful to inject separately to the soil conditioning agents a filler-suspension doped with structuring polymers.

3 - EXAMPLES OF EPBM JOBSITES IN CLAYEY SOIL

A good example for the effectiveness of dispersing agents is the MetroSur project in Madrid (ESP). Nearly all working EPB machines - Herrenknecht as well as NFM machines - reported at the end of the year 2000 very low advance rates of around 5-15 mm/minute due to clay clogging. The cutterhead was plugged mainly in the centre region and the working chamber was filled with re-agglomerated clay lumps. In consequence not only the advance rate was very low but also the necessary cleaning procedure every weekend was very costly and not favoured by the operating personal. It was clear that the soil conditioning only with Foam would never solve these type of problems.
The situation only improved when a newly developed clay dispersing additives was added.
No clogging at all was detected after 1 week advance with TBM speeds of more then 50 mm/minute!
What seemed to be a problematic TBM-drive before, finally turned into breaking the old Channel-Tunnel Rail Link EPB world record:

- TBM diameter: 9,33 m
- 936m in 31 days

Details can be found in figure 4 and by consulting the website www.ugc.mbt.com


MBT—Online

Metro Madrid – world record

The solution

The challenge
The clayey soil found under Madrid was adhering to the cutterhead and in the working chamber. This resulted in slow advance rates and high maintenance due the need to

The result

The outcome of this was the claim for a new world record for EPB tunnelling from FCC with 509 metres driven in 31 days. The previous record was held by the Channel Tunnel project, but with a smaller diameter TBM.

MBT International Underground Construction Group would like to thank FCC for permission to make this article and congratulate them on their success.

degussa. Construction Chemicals Division

figure 4 – FCC world record drive

4 - EXAMPLES OF EPBM JOBSITES IN POROUS SOIL

Two good examples of the successful use of EPB machines in porous soils are the Botlek (NL) drive [2] where polymeric Foam was used as well as on the Aviles (ESP) drive. Despite the fact that both drives have been completely different regarding type of TBMs, and soil conditioning techniques used, both worked successfully in a soil type which 'before' had required Slurry technology.
The Aviles drive was constructed using a Lovat machine (∅=3,40 m) under 3,0 bar sea water pressure. The particle size distribution is shown in figure 5. Detailed information about this project is given in [3]

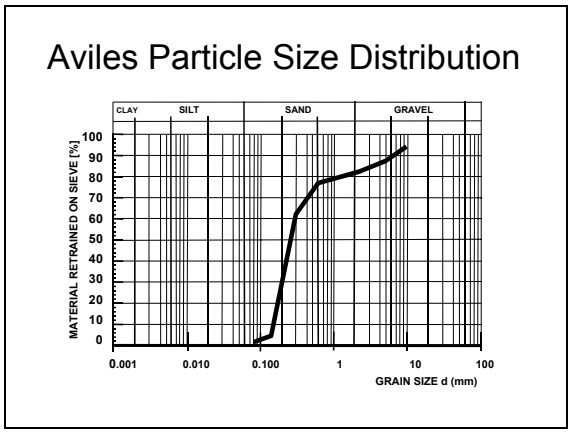

figure 5 – Aviles project particle size distribution

The answer to the question 'Why an EPB machine had been chosen for this project' is the fact that the TBM, before reaching this type geology, went through a long distance of clay silts. In consequence the TBM cutterhead was not suitably adapted to sandy gravels and high water pressure. In contradiction, the Botlek machine where the sand geology dominated the drive, the machine design was specified accordingly. But nevertheless also in Aviles it was possible to drive through this 1.500 m long 'fault' zone by using a combination of a structuring polymer and a special tunnelfoam. The TBM speeds reached up to 80 mm/min without having problems with incoming water.
For another project - BPNL Lyon (F) with an NFM machine ∅=10,98m - an additional filler-suspension was used during an intermediate section of gravelly sand. Details are given in [4].

5 - CONCLUSION

As a consequence of sophisticated soil conditioning additives, EPB machines can be used in more porous and also in inhomogeneous soils (see *figure 6*).

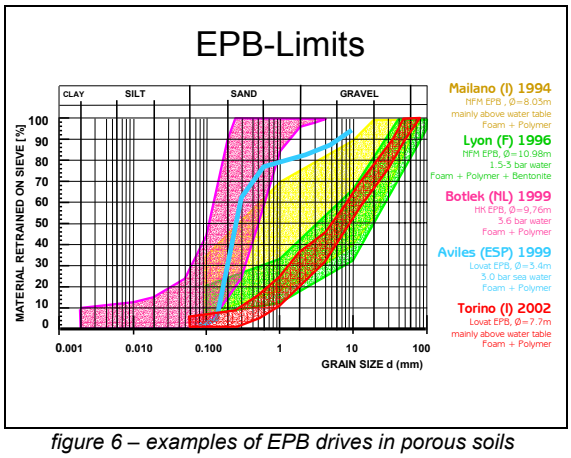

figure 6 – examples of EPB drives in porous soils

The Milano (I) 'Passante Ferroviario' EPB-drive was ahead of time when constructed in 1994. A part of the described problems [5] could now be solved by using modern soil conditioning additives. This will be proven by the Torino Metro (I) project (see figure 6) which as a quite similar geology and will be realised with EPB machines. The project is supposed to start in autumn 2002.

6 - OUTLOOK

Will the future of soft ground TBM tunneling be the Slurry or EPB technique?
Maybe there will be a combination of both for porous soils: Why not use a suspension only made of the original soil together with new conditioning additives – perhaps with a little help of a fine filler – without Bentonite and in consequence without separation plant. The advantage will be tremendous!

7 - REFERENCES

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[3] Langmaack L. (2001), Einsatz neuer TBM-Konditionierungsmittel, Messe München International, Verlag Glückauf GmbH, pp 27 ff

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[5] Marcheselli P., Peron J.E., (1995), Construction of the ‚Passante Ferroviario' Link in Milano, RETC proceedings, pp. 459 ff