The boulder facts of life

US-based geotechnical and underground construction consultant Dr Peter J Tarkoy looks at some of the problems, impacts and solutions associated with boulders in mechanical – and especially micro-tunnelling

Figure 1

CANADA and the northern portion of the US have been glaciated. Consequently, a variety of glacial materials have been deposited, most notably cobbles and boulders, while the bedrock has been disturbed with rock blocks that have been dislodged and rotated.

Boulders in soil tunnelling have a long history and great notoriety. Boulders in microtunnelling have a shorter one, yet that history is much more notorious in terms of time and cost overruns, adversarial relationships and, most notably, finger pointing.

I make no apologies for presenting an opinion that is self-evident, but my experience suggests that this fact is unpalatable and ignored in many circles. The facts of life regarding boulders are:

- Some geological regimes inherently contain boulders such as glaciated terrain
- Boulders are generally harder than the indigenous rocks since they have survived being transported from long distances
- It is difficult to identify boulders in borings, even when cored
- Tunnel construction must always anticipate boulders in glacial or boulder-prone terrain
- Ignoring the presence of boulders during any project stage, especially when planning the excavation, will have a monumental, adverse impact on tunnel costs.

There are many unaddressed issues blanketing the realities of tunnelling and microtunnelling in geological regimes that contain cobbles, boulders and rock blocks.

Dowden and Robinson (2001) describe a machine encountering boulders as follows: "When a full-face machine encounters a boulder, there are a number of possibilities. If the boulder is not too large, it can be ingested by a properly designed TBM mucking system. If the boulder is too large to be ingested, and the ground is firm, it may be broken up by a suitably equipped machine cutterhead. If the soil matrix is weak, the boulder may be dislodged, and it may either be pushed radially outward by the rotary action of the cutterhead, and beyond the tunnel periphery, or it may stay in the face area and eventually block further progress of the machine until it is manually removed. Depending on the prevailing face condition and cutterhead-chamber configuration and accessibility, manual break-up and removal can be relatively easy or very time-consuming."

GEOTECHNICAL REALITIES

The facts of life regarding geological conditions are that:

- Cobbles and boulders are common in many geological regimes, such as glacial till
- In glaciated areas, loosened and discontinuous bedrock blocks may occur near the top of the rock in the soil matrix

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Figure 2a

Figure 2b

- It is difficult to identify cobbles, boulders and rock blocks by size, frequency and distribution
- It is difficult to sample, test, and identify intact properties of boulders.

The foregoing are indisputable geological facts, and their adverse impact can only be ameliorated by professional intervention and sound contractor practices.

COBBLES, BOULDERS & ROCK BLOCKS

The facts of life about cobbles, boulders and rock blocks are that:

- Design and geotechnical engineers are hampered because physically encountering cobbles, boulders and rock blocks is unlikely during exploration with boreholes
- Cobbles, boulders and rock-block sizes are not easily identifiable through borings
- Cobbles, boulders and rock blocks vary in size
- Rock-block shape and extent are not easily identifiable in general
- Cobbles and boulders are general harder than the indigenous rock since they have survived a long trip through glacial or fluvial transport.

Similarly, the adverse impact of cobbles, boulders and rock blocks can only be minimised or even eliminated by professional intervention through design and planning.

TUNNEL & MICROTUNNEL CONSTRUCTION

The impact of cobbles, boulders and rock blocks on mechanical tunnelling is related directly to the size of the machine and its cutterhead design. There are only four ways to deal with boulders:

- 1. Removal by hand from an accessible-faced machine
- 2. Ingestion of the boulder into the crusher to comminute into smaller pieces
- 3. Chip the boulder in front of the rock cutterhead, equipped with rock cutters by design
- 4. Dig up the boulder from the surface.

Solution 1 is possible only when the diameter is large enough for man-entry and the soil matrix is stable for the entire drive; otherwise an open-faced machine could not be used. Solution 2 may be effective only if:

- Boulders are small relative to tunnel diameter
- Boulders are soft enough to crush and
- Boulders move easily into the crushing chamber.

Solution 3 is the safest since it is not affected by size, location, hardness or frequency. The chipping of large boulders results in material being easily transported through the intakes and slurry line of the system, as illustrated in Figure 1.Solution 4 is not a solution; it is an unfortunate consequence of a lack of planning. Presumably, the reference to tunnelling refers to mechanical excavation with man entry into the heading.

Figure 3

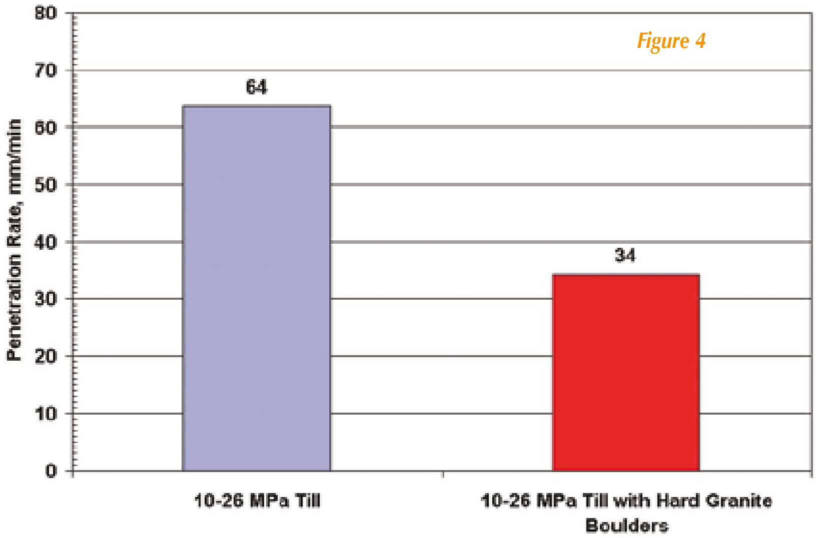


Figure 4

BOULDERS

The facts of life regarding boulders in tunnel excavation are that:

- Boulders will, in fact, be encountered in tills, outwash materials and boulder-producing, geological materials
- Boulders are generally too large for effective ingestion into a microtunneller
- Boulder ingestion is:
  a. Impossible by machines of < 1m diameter.
  b. Difficult by machines of 1-2m diameter
  c. Inefficient by machines of < 3m diameter or with limited cutterhead openings
- Boulders become even more difficult to excavate efficiently in a soft or granular matrix because they will move around.

Inherently, the excavation of boulders in tunnelling is less efficient than excavating the matrix in which they occur. An example of delays caused by boulders, even in a tunnel as large as 3.5m in diameter, is illustrated in Figure 2. A project in glacial till was expecting to encounter boulders (as per the bill of quantities). Consequently, the micro-TBM had to excavate unusually hard till with very hard boulders of various sizes. The chosen cutterhead design assured that it could deal with:

- Boulders of any size
- Very hard boulders (200-300 MPa)
- Boulders at any location in the face.

Consequently, it was obvious that the only assurance of success would be to use a cutterhead that would comminute boulders in front of it, without having to rely on ingestion and the crusher. The chosen cutterhead design, illustrated in Figure 3, ensured any boulder or rock encountered would be cut by the rock-cutters in front of the machine, regardless of the boulder's location in the face.

In fact, the machine encountered a very hard boulder that was cut for a tunnel length of 8m. The system was so effective that the penetration rate in granitic boulders (200-300MPa) was reduced by only 47% of the penetration rate experienced in the very hard till (10-26MPa), as illustrated in Figure 4.

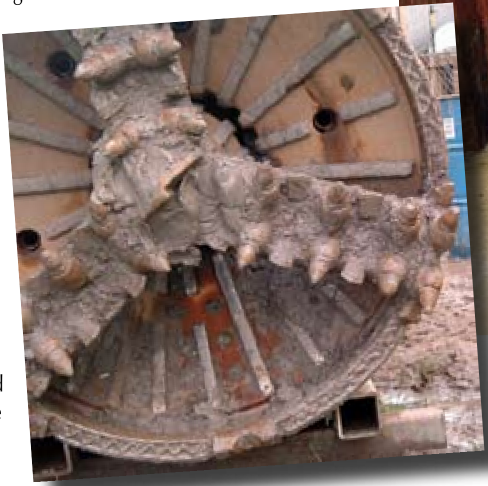
Various micro TBM cutterheads illustrated in Figure 5 were not designed or selected to deal with boulders and show there is a considerable productivity penalty (57% reduction, not including rescue shafts), as illustrated in Figure 6.

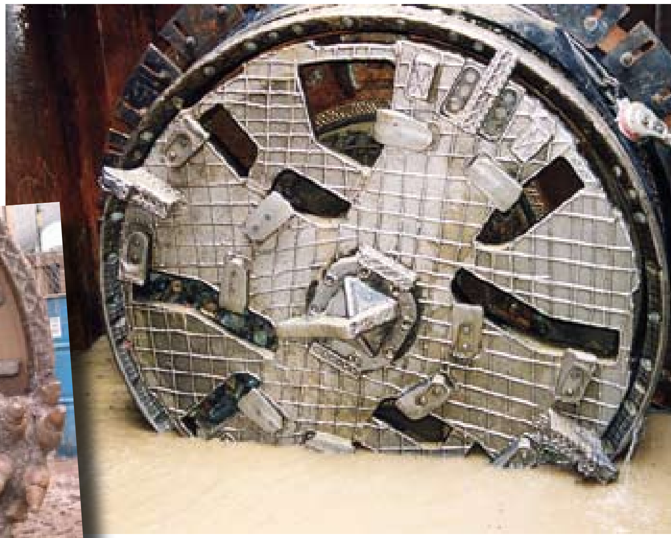
In addition to the lower penetration rate in Figure 6, substantial unnecessary costs and delays were sustained when rescue shafts were necessitated as a result of poor equipment choice. Furthermore, in some instances, boulder/rock blocks have torn off cutterhead arms and caused other damage.

It becomes clear that the difference between success and failure when dealing with boulders, especially in microtunnelling, is the planning and selection of appropriate cutterheads by a contractor who has a contractual relationship with the owner. The machine maker is not a party to the contract, so machine selection by a manufacturer accrues responsibility to the contractor.

ROCK BLOCKS

Rock blocks will, in fact, be encountered in tills near the top of the rock where the glaciers have plucked, separated and rotated blocks from the underlying bedrock. Rock blocks may also be encountered in areas of mass wasting. Rock blocks are almost always too large for effective microtunnelling ingestion; therefore, they must be effectively cut in front of the cutterhead.





Figures 5a (below) and 5b (right)

SOLUTIONS, PREVENTION & RESPONSIBILITIES

Solutions, preventions and responsibilities inherently belong to the geotechnical engineer, design engineer and contractor. The geotechnical engineer is charged with the description of the anticipated conditions from available data and exploratory investigations. However, since boulders, rock blocks and their →

strength are difficult to define specifically, there are limitations to the effectiveness of the exploration.

Effective solutions by the design engineer are to provide:

- Warnings
- Contract language (specifying materials to be excavated)
- Minimum machine requirements for dealing with boulders and rock.

As a result, project conditions are represented by a level playing field and leave little room for overly optimistic interpretation by various contractors, local or national. It is also necessary for the engineer to issue addenda when contractors provide notice of inconsistencies in local and project-specific conditions.

Contractors must address, reconcile and be responsible for:

- Contract requirements
- The slightest indication of boulders and rock blocks
- Their own experience with local, geological conditions in glacial till containing boulders, with rock blocks above top-of-rock
- Providing notice and/or request clarification if their local experience is inconsistent with contract and associated data.

Figure 5c

CONCLUSION

Boulders should no longer cause problems for contractors if these have resulted from the micro TBM manufacturer's poor selection of cutterheads for dealing with boulders. Neither should a contractor's circumventing boulder conditions, indicated in the contract, become the responsibility of the owner through a differing site condition claim. It's time that the realities of boulders encountered in microtunnelling projects are dealt with in a responsible and professional manner by all parties.

References:

Dowden, P.B. & Robinson, R.A. (2001), Coping with Boulders in Soft Ground Tunneling. In Hansmire, W.H. & Gowring, I.M. (eds). Proceedings 2001 Rapid Excavation and Tunneling Conference, Littleton, Colorado: SME., pp961-977. Tarkoy, P. J. (1990-2006). Project documents and case histories.

Figure 6