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Introduction

During the excavation of the starting rooms (in the North and the South directions) at the bottom of the second shaft, important slip planes were observed. The aim of this report is to assess if the origin of these discontinuities [1] is natural or is due to the modification of the mechanical stress state, induced by the excavation process.

Generalities

Engineers who excavate into rock are faced on one hand with naturally occurring planes of weakness crosscutting the rock mass (bedding and slip planes, joints and shear zones, …) and on the other hand with new fractures by virtue of stress readjustments due to the excavation process (Goodman, 1980). The fracture pattern depends on the shape of the excavation, on the excavation process (phases, progress rate, ...), on the depth below the surface and on the strength properties of the rock mass around the excavation.

An example is the construction of the Mt. Terri research laboratory (Opalinus Clay in Switzerland). The mapping fractures on drillcores and during the excavation works (galleries and niches) revealed two classes of discontinuities: single tectonic faults and artificial fractures (see Fig. 1). Two groups of artificial fractures were observed. The first group consists of quite recent fractures, oriented parallel to bedding and formed during the excavation of niches by pneumatic hammering. The second, much more important group of artificial fractures, are the so-called unloading fractures. Unloading fractures consist of joints and shear fractures, formed by plastic deformations in the tunnel wall due to tunnel convergence (Thury and Bossart, 1999).

Natural discontinuities in Boom Clay from a geological point of view

The Boom Clay is characterised by a rather constant chemical and mineralogical composition (Vandenberghe, 1978). However, there are variations in grain size, organic matter, and carbonate content, resulting in the typical layering of the deposit. The variations reflect changes in local tectonics, eustacy and climate, and are associated with Milankovitch cyclicity (Van Echelpoel, 1991).

Sediment deposits might be affected by polygonal patterns of extensional faults detected by seismic reconnaissance as mentioned by Vandenberghe (1998) based on work done by Cartwright and Lonergan (1986). In the Northeast of Belgium no such a fault system has ever been described in the Boom Clay Formation.

Boom Clay has been affected by tectonic faults related to the Roermond Graben. These faults are essentially oriented in an NNW-SSE direction. They are mostly found in the Paleozoic and

[1]: In this text, discontinuity is used in the geomechanical sense and regroups weakness plan and fracture

Mesozoic basement and closer to the Graben but some satellite faults are found in the Poppel, Mol and Lommel area and have been reactivated during Tertiary up to Miocene and Quaternary. These faults have been determined on the basis of seismic profiles where a clear throw could be seen or sometimes on the throw deduced from a difference in a layer depth between two boreholes (Demytennaere, 1989; Demytennaere and Laga, 1988; D'hooge et al, 1991; Gullentops and Vandenberghe, 1995). Some evidence can be found for the Mol Rauw and Poppel faults in the geomorphology (Vandenberghe, 1982). A more recent seismic exploration has been performed in the nuclear zone of Mol-Dessel to detect these large scale features (Wouters and Manfroy, 1998). Its interpretation is still in progress.

In the Boom Clay, Vandenberghe (1998) has recently noticed one particular flat-lying fault in a clay pit (Kruibeke) near Antwerp and the Scheldt valley. Its origin is not understood but might be linked with diapirs in the Scheldt valley. Other specific structural features were described in the area of Ramsel and are related to the incision and filling up of the tidal gully during the Diestian (Vandenberghe and Vandenberghe, 1979). There is no erosion gully or diapirs features observed in the Mol area.

On a smaller scale, discontinuities are mentioned as possible features encountered in the clay sediments submitted to decompaction or erosion. A cleavage can then appear parallel to the bedding. This is observed generally in outcrop zones (Vandenberghe, 1998).

Previous seismic, geophysics, coring investigations in Boom Clay under the Mol-Dessel site have never shown weakness planes or faults except the formation bedding.

Observation around excavation

During the construction of the Test-Drift (1987)

During the excavation of the Test-Drift (1987), discontinuities were observed (mainly on the lateral walls) in the clay mass (see Pictures 1 and 2). These discontinuities were without consequences for the stability of the gallery although their presence caused some problems during the digging works and led to a slightly larger excavation profile at the roof. The orientation of the discontinuities was systematically registred (mean orientation: strike direction N100 dipping 16S). It was concluded that all fracturation planes encountered in the gallery are resulting from a combination of the stress-state of the pre-existing fractures of Boom Clay and new decompression planes due to the excavation (Van Cotthem, 1988).

During the construction of the second shaft (1998-1999)

During the excavation of the second shaft (1998-1999), sub-horizontal fractures were observed on the lateral wall dipping towards the centre of the shaft (see Picture 3). The fractures were symmetric around the axis of the shaft. The length of the fractures ranged between a few cm to 100 cm and was not continuous on the circumference. Fractures were opened about 1 mm and spaced about several meters.

Neither discontinuities nor slip planes were observed on the excavation front (even after a one-week stop of the excavation works).

During the enlargement of the foundation, detachment of large clay blocks and slip planes (similar to those encountered during the excavation of the starting rooms on the bottom of the shaft) were observed - see Picture 4. At this time, the encountered slip planes did not cause major problems to the contractor.

During the excavation of the starting rooms at the bottom of the shaft, large slip planes (about the whole section of the gallery: ~ 7 m) have been observed both on the North and the South side. They consist of an interconnected network of conjugated planes (N90- 35N; N90-35S). This direction is different from natural fractures. It could be interesting to compare these directions with the directions of the fractures observed in open pit. The circular shape of the slip planes (as we can observe on Picture 5) leads to think that the fractures are symmetric around the shaft axis. They were visible on the front and on the lateral sides (see Pictures 5, 6, 7). The fractures were initially closed and were opened during the decompression process up to detachment of some blocks (see Picture 8).

Slickensides (kind of polish, with linear grooves and ridges parallel to the direction of the movement, see Fig. 2) were visible on the slip surface. The shape of the grooves and the ridges indicated a movement in the direction of the centre of the shaft, which can be related to the decompression of the massif (see Fig. 3).

During the RESEAL experiment (1999)

For the purpose of the shaft sealing experiment RESEAL, a part of the lining of the small shaft in HADES has been removed. During this operation a clay block (about 50 cm) has detached along a slip plane (N45E 45N - same type that those encountered during the construction of the starting gallery).

How the observed fracturation can be explained

From the above observations some conclusions can be drawn:

Observations	Conclusions
no slip planes were observed on the front of the shaft during its excavation – fractures (other than those created by the drilling process itself) were never observed on drillcores (except once DOEL – 2B)	
the slip planes were circular shaped	➢ a circular shape is not expected for a natural fracture and indicates a symmetry around the shaft axis
	➢ pre-existing discontinuities play a minor role in the orientation of the fractures induced by the excavation
no fractures have been observed following the bedding planes and/or its conjugate direction	➢ the grooves and ridges on the slickensided surfaces show a movement of the blocks towards the shaft centre from all directions towards the shaft centre
➢ we expected that pre-existing fractures should be visible during excavation	

- movement towards the shaft centre is in agreement with the effects of the decompression (see Fig. 3)

Even if up to now Boom Clay seems to be a homogeneous geological formation at the Mol site, we cannot exclude that weakness planes other than the bedding one exist. However, they seem to play a minor role in the fractures observed during the excavation of the starting rooms. The symmetry around the shaft indicates that the fractures are induced from the *in situ* stress state readjustments during the construction of the shaft.

The large excavated diameter of the shaft (8.6 m on the level of the starting rooms) and the important convergence allowed (about 30 cm on the diameter) has led to a large decompression of the rock. The low total pressure recorded on the lining (less than 0.4 MPa) has confirmed it.

No active support was installed from the beginning of the excavation works of the starting rooms. Indeed, in the first excavation phase, support was installed mainly to protect the miners and not to limit the convergence. This and the low excavation rate have surely favoured the opening of the pre-existing fractures and/or the induction of new fractures due to the excavation. The installation of an active support in the last excavation phase has considerably improved the behaviour of the rock.

Conclusion

The fractures observed during the excavation of the starting rooms are probably the result of *in situ* stress state readjustments due to the construction of the second shaft. Further modelling of the excavation of the shaft could help to better understand the failure mechanisms leading to the fracturation of the rock.

The observations realised during the construction of the second shaft have to be confirmed by a better characterisation of the fractures. Seismic campaign and permeability measurements are foreseen from the starting rooms to better characterise and to assess the extent of the fractured zone. The fractures will be investigated more in detail if such fracture planes will be encountered during the construction of the connecting gallery.

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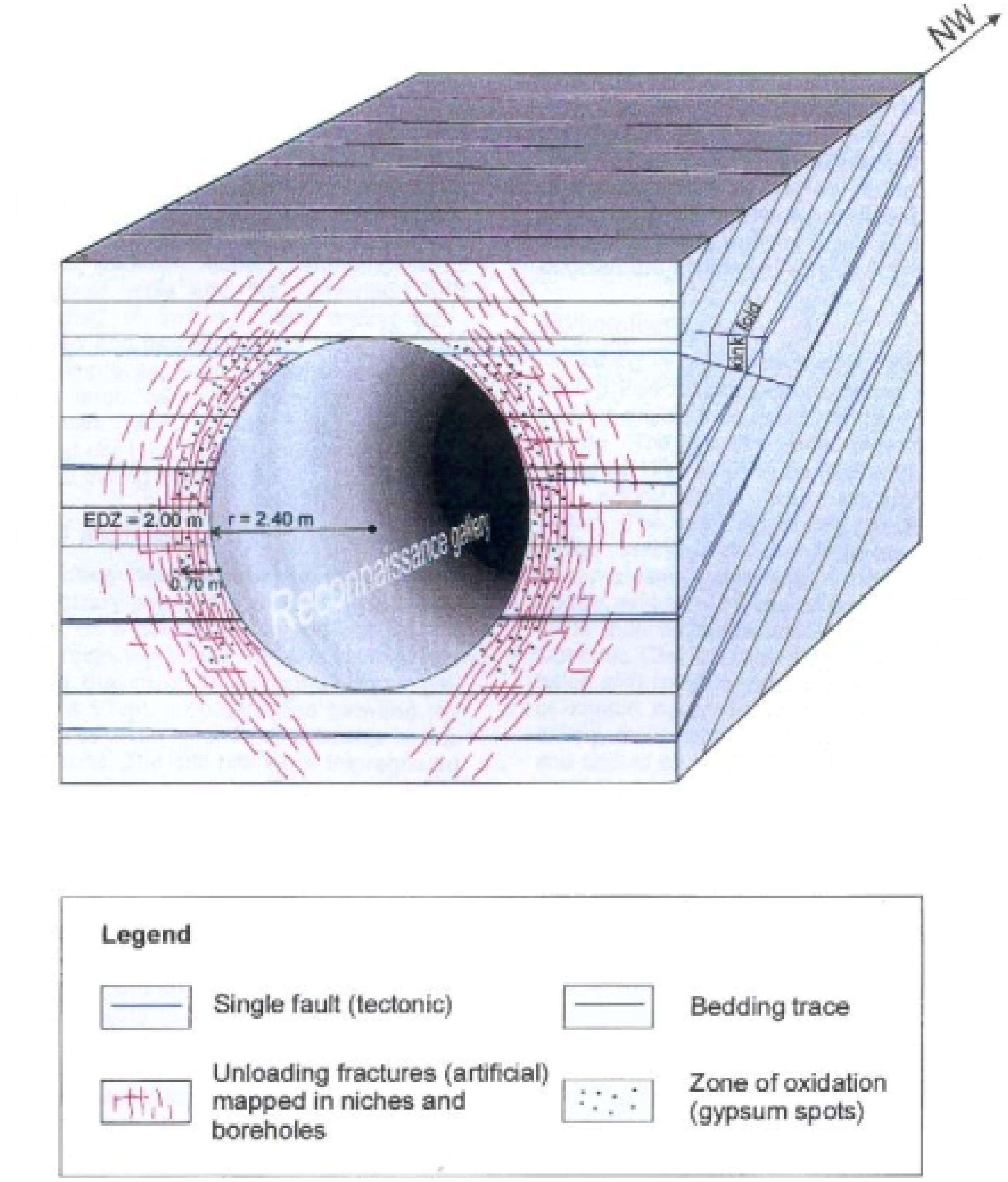


Figure 1: Three dimensional sketch of fractures identified around a gallery (Mt. Terri –Thury and Bossart, 1999)

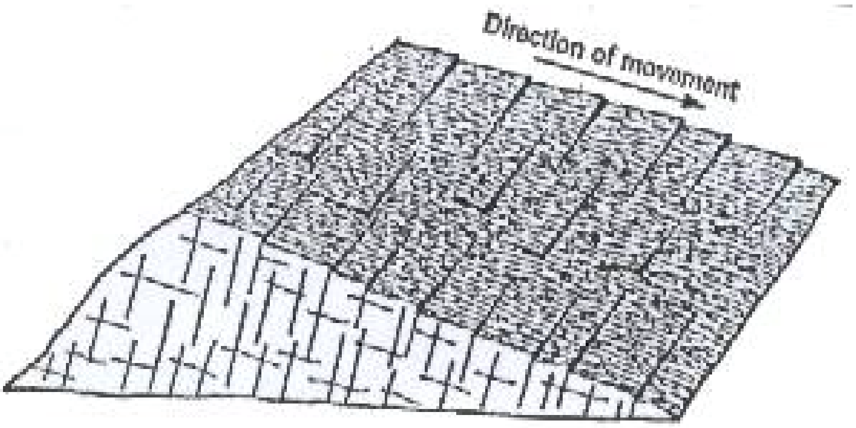


Figure 2: A slickensided surface (Whitten and Brooks, 1972)

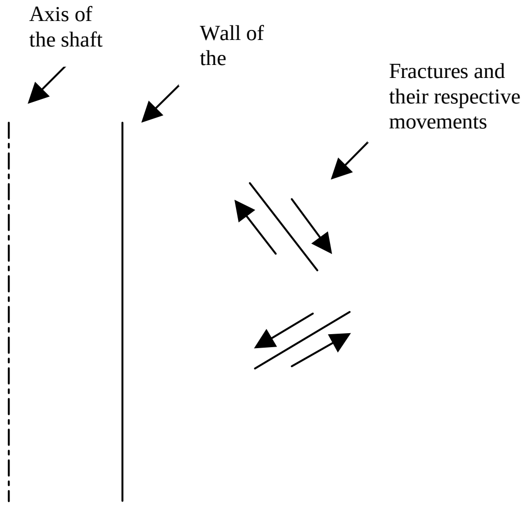
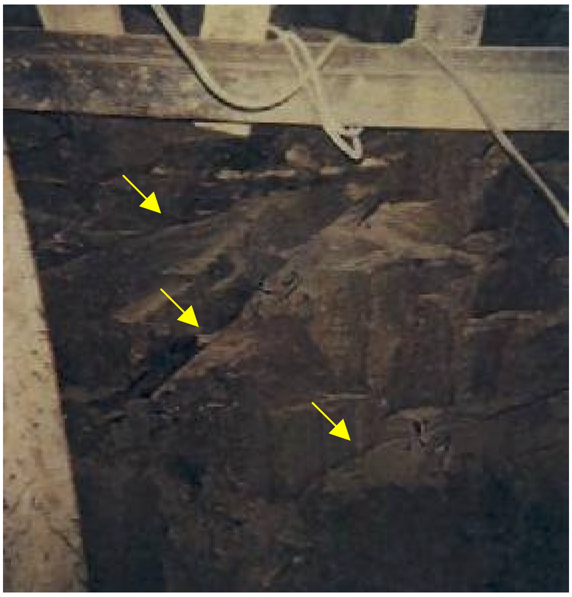


Figure 3: Fractures and their respective movements around the shaft

Picture 1: Fractures observed during the excavation of the Test Drift (1987) – East lateral wall



Picture 2: Fracture observed during the excavation of the Test Drift (1987) – West lateral wall

Picture 3: Degraded rock on the lateral excavated wall of the second shaft (1998)

Picture 4: A slickensided surface observed during the enlargement of the foundation (1998)

Picture 5: A slickensided surface circular shaped observed in the South starting room (1999)

Picture 6: A slickensided surface circular shaped observed in the South starting room (1999)

Picture 7: Fractures observed on the lateral wall of the South starting room (1999)

Picture 8: Void created by the detachment of a large clay block at the front of the South starting room (1999)