Technology Trends for mechanised Tunnelling in loose Rock

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Since the 1970s in particular mechanised tunnelling technology has been increasing its share of the market at the expense of conventional tunnel engineering, a trend that has seen the development of ever larger tunnelling shields. The paper analyses some 274 individual projects in order to assess the impact of key machine parameters such as shield diameter, drive power, torque and rate of advance. It also traces the way in which these various parameters have developed over time.

Tunnelling • Mechanised tunnelling • Loose rock • Development

1 Introduction

The idea of building a tunnelling shield was first proposed by Sir Marc Isambard Brunel in 1806. The structure in question was rectangular in section and comprised twelve supporting frames that were divided up in such a way as to create three separate working chambers [1]. Each chamber had sufficient room for a miner whose job it was to excavate the soil from the working face. This particular arrangement was capable of achieving a rate of advance of 3 to 4 m of tunnel a week [2].

Some 200 years have now elapsed since the tunnelling shield was first introduced and the intervening years have seen huge advances made in the mechanised tunnelling industry. The material that comprises the heading face is now excavated in a single pass by means of a circular cutting wheel. The working face itself may be secured in various ways, which may involve using slurry, liquid or compressed air, while steel-concrete tubbing elements are installed to provide support along the line of the tunnel. Projects of this kind can achieve impressive rates of advance, with 360 m being completed in a single week, for example, during the construction of new Barcelona metro line 9 [3].

By investigating as many as 274 projects involving the use of tunnelling shield systems from various manufacturers it has been possible to analyse the way in which machinery and equipment has developed within the mechanised tunnelling sector. This study was based on an examination of the following parameters:

- Shield diameter
- Drive power
- Torque
- Rate of advance

The various data were plotted as a function of their development over time. The evaluation first considered the projects regardless of the type of shield machine being employed. Individual aspects of the projects were then analysed separately so that the overall data could differentiated into two groups: one comprising slurry shield tunnelling systems/'mixshields' and the other earth pressure balance shield systems.

2 Shield Diameter

Fig. 1 presents an overall view of how the shield diameters of various types of tunnelling shield system developed over the years from 1869 to 2019. This representa-

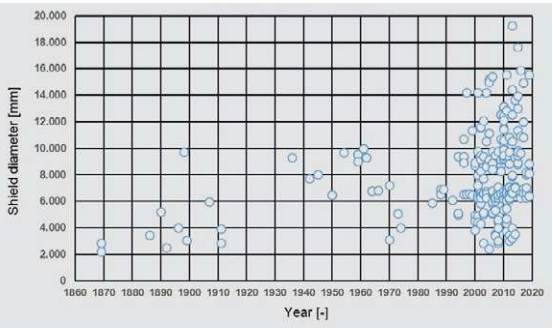


Fig. 1: Developments in the shield diameter (271 projects)

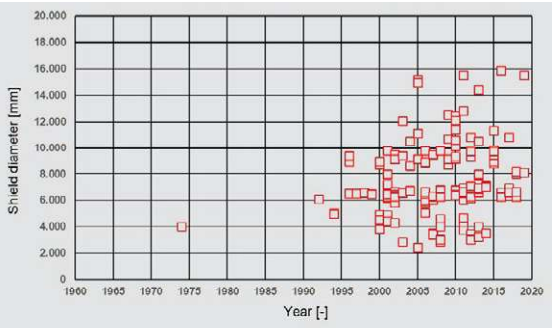


Fig. 2: Developments in the shield diameter of earth pressure balance tunnelling machines (166 projects)

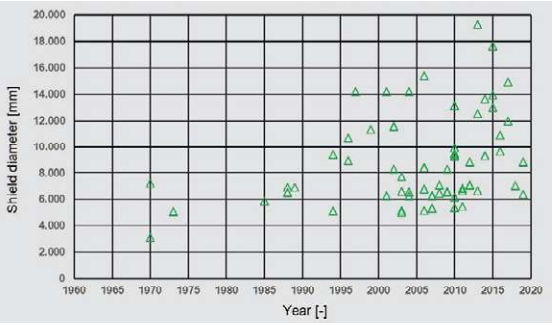


Fig. 3: Developments in the shield diameter of slurry shield tunnelling machines/mixshields (75 projects)

tion is based on some 271 individual projects. It clearly shows that shield diameters have increased continuously since the 1990s. Here it is worth highlighting two of the most significant projects in this respect, namely the Tuen Mun-Chek Lap Kok link tunnel in Hong Kong, which was constructed using a 17.63 metre-diameter shield, and the Orlovski Tunnel in St. Petersburg, where the tunnelling shield had a diameter of 19.25 m. **Fig. 2** traces the development of tunnelling shield diameters over the period 1974 to 2019, with the focus here on earth pressure balance shield systems, and **Fig. 3** records how slurry shields and mixshields developed between 1970 and 2019. The increase in shield diameter can be attributed to the demand e. g. for multi-lane road tunnels and/or multi-deck traffic levels. As the following analysis confirms, the increase in shield diameter led to higher drive outputs and torque ratings at the cutting wheel.

3 Drive Output

The drive output of a shield tunnelling machine is defined as the total power generated by the cutting wheel drive in excavation mode. An examination of the way that drive performance evolved during the period 1986 to 2019 (**Figs. 4 and 5**) shows a fairly consistent picture, with most projects of this kind using equipment with a drive output of no more than about 4,000 kW. There are, however, individual projects, such as the M30 southern bypass north tunnel in Madrid and the Sparvo Tunnel between Bologna and Florence, where the installed drive power was 12,000 kW.

4 Torque

The cutting wheel has to have sufficient torque to be able to detach the soil material from the tunnel face. Here the design of the cutting wheel and its cutting tools have a decisive influence on the level of torque required. An analysis of the way that torque ratings have developed over the years shows a trend similar to that of the drive output levels. Here too the majority of tunnelling schemes involved torque levels of up to about 40,000 kNm (**Figs. 6 and 7**). However, there were also two notable projects, namely the M30 southern bypass north tunnel in Madrid and the Santa Lucia road tunnel near Florence, where the torque rating was 95,923 kNm and 101,296 kNm respectively.

5 Rate of Advance

Obtaining information on the tunnelling performance, or the rate of advance in terms of metres driven per day, is a very complex process because of all the different factors that have to be included. For example, it is necessary to consider whether the tunnelling operation has been based on an 8-hour working shift or has been designed to run continuously around the clock. Geology will also play a key role. The cutting tools will have to be changed over, depending on the amount of wear they have suf-

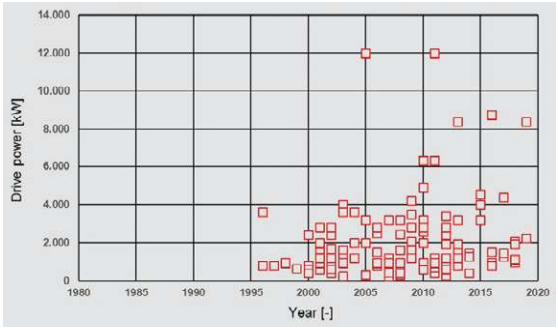


Fig. 4: Developments in the drive power of earth pressure balance shield machines (147 projects)

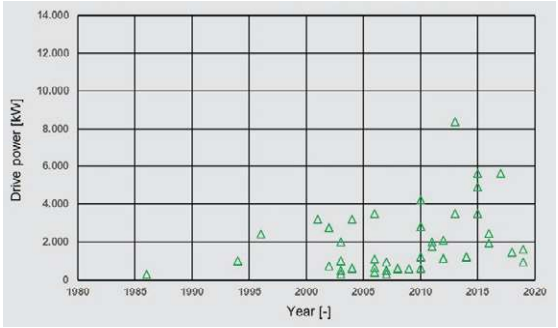


Fig. 5: Developments in the drive power of slurry shield tunnelling machines/mixshields (51 projects)

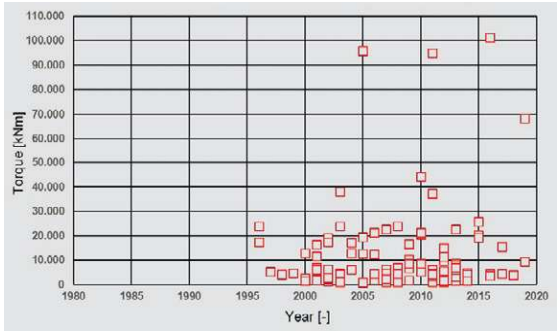


Fig. 6: Developments in the torque rating of earth pressure balance shield machines (139 projects)

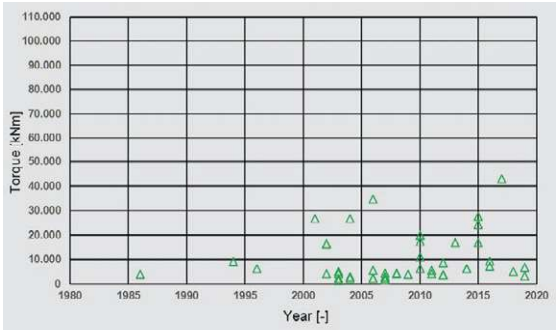


Fig. 7: Developments in the torque rating of slurry shield tunnelling machines/mixshields (49 projects)

fered, and this operation will require scheduled periods of machine downtime. Malfunctions of various kinds can also occur, leading to unanticipated stoppages.

Figs. 8 to 10 show both the average values and the extremes. The average rates of advance were determined on the basis of sections of tunnel completed without disruptions or incidents, that is to say with no unforeseeable stoppages. The extreme values relate to short sections of tunnel drivage where peak results have been obtained. The figures do not make any allowance for, or factor-in, whether the daily performance was achieved within an 8-hour shift or as part of a continuous cycle of operations. The values shown should not be used as a basis for a construction-time costing exercise but rather are intended to reflect the range of possible results.

It is clear that in the pioneering years of mechanised tunnelling performance rates were at a fairly low level (Fig. 8). From the 1950s on tunnelling performance figures began to increase steadily and by 1995 it was obvious that very high peak rates of advance were being obtained in the tunnel construction industry. A comparison between the earth pressure balance shields and the slurry shield/mixshield boring machines shows that higher peak performance rates can be achieved with the earth pressure balance shield machines (Figs. 9 and 10).

6 Interdependencies

As explained in section 2, the progressive increase in shield diameter over the years has meant that higher drive outputs and torque levels have been required at the cutting wheel. Figs. 11 and 12 show how the drive output required for both earth pressure balance machines and slurry shield machines/mixshields is related to the diameter of the shield in question. The relationship between the torque applied at the cutting wheel and the diameter of the tunnelling shield is also illustrated in Figs. 13 and 14, here too with reference to both earth pressure tunnelling machines and slurry shield machines/mixshields. The clear link between the size of the shield and the drive power and torque applied at the cutting wheel is illustrated in Figs. 11 to 14.

The relationships involved can be described by using various regression functions, these being presented

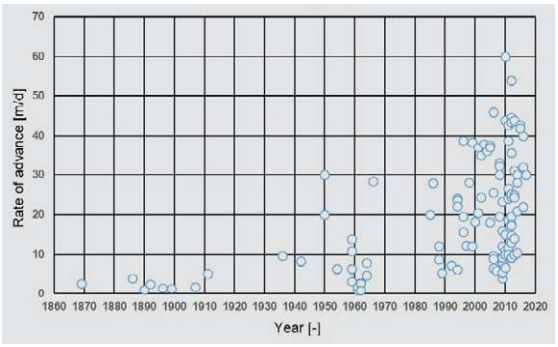


Fig. 8: Developments in tunnelling performance (115 projects)

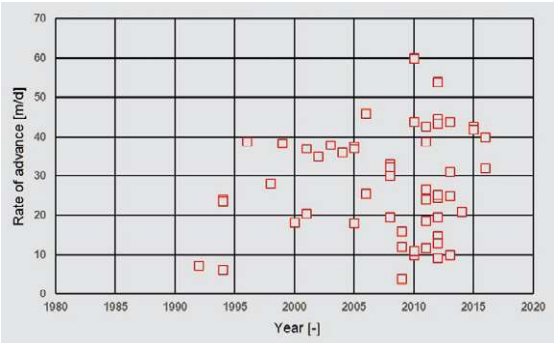


Fig. 9: Developments in the tunnelling performance of earth pressure balance shield machines (55 projects)

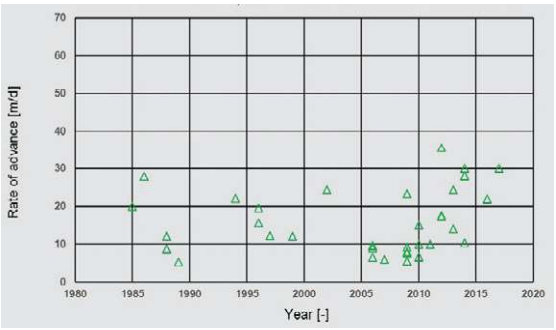


Fig. 10: Developments in the tunnelling performance of slurry shield machines/mixshields (34 projects)

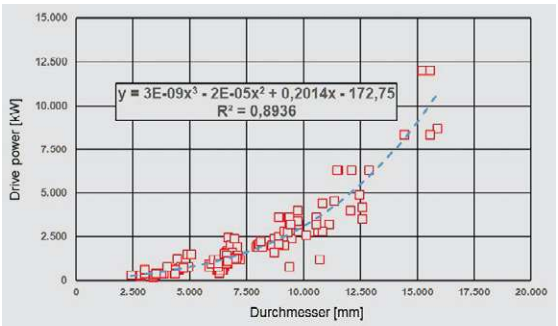


Fig. 11: Drive output of earth pressure balance machines in relation to the shield diameter (147 projects)

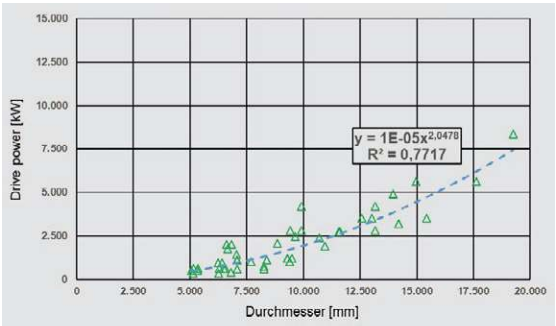


Fig. 12: Drive output of slurry shield machines/mixshields in relation to the shield diameter (50 projects)

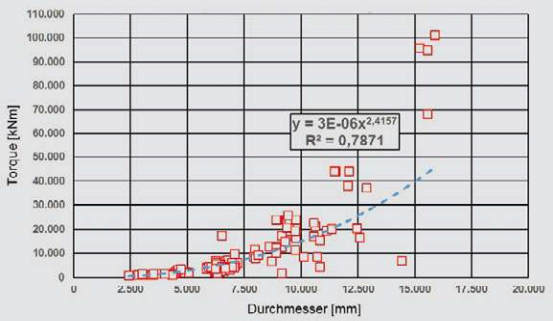


Fig. 13: Torque rating of earth pressure balance shield machines as a function of the shield diameter (139 projects)

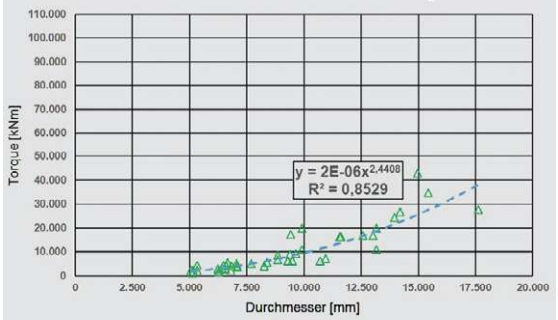


Fig. 14: Torque rating of slurry shield machines/ mixshields in relation to the shield diameter (48 projects)

in **Figs. 11 to 14**. The coefficient of determination R^2, which is a quality factor for the regression function, is also given in **Figs. 11 to 14**.

7 Summary

The last 25 years have seen enormous advances made in the technical performance of shield tunnelling machines. Analyses indicate that this development is not yet nearing its peak and there are still no signs that we are reaching the technical limits of this technology. The scientific community can therefore look forward in anticipation to further exciting developments taking place in this sector in the years ahead.

8 References

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