REVIEW OF CUTTER WEAR-CONSUMPTION AND SPECIFICATION USED IN THE HSUESHAN TUNNEL TBM EXCAVATION

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ABSTRACT

Hsuehshan Tunnel, 『a renowned difficult project in the world』 as recorded in the British Encyclopedia. Even such a single cutting tool as Cutters, the specification had been revised several times against the various rock formations and different Full-face and Top-heading mining methods used for TBM excavation especially in Szeleng Sandstone. This paper presents our methodology and experience of choosing the appropriate Cutters to overcome all the difficulties and problems arose in mining through this tunnel, with the hope to provide tunnelling and underground construction field experts for references for the future.

INTRODUCTION

The 12.9 Km long Hsuehshan Tunnel is composed of 2 main tunnels (westbound and eastbound) and a pilot tunnel. In view of the environment constrain, all 3 tunnels were originally planned to be bored by TBMs (Tunnel Boring Machines) from the eastern portal and head west. It pass under the Hsuehshan Ranges in northern Taiwan, in the tunnel horizon, it cut across strong, hard, abrasive and intensely fractured Szeleng Sandstone on the east and indurate sandstone and siltstone on the west. On the September of 1996, eastbound main tunnel TBM was assembled and launched to the mining face and began the boring operation. But, due to the extremely poor ground stretch of Shanghsin Fault as well as other identified water-bearing faults such as Paling, Tachingmen, Shihpai, and Shihtsao Fault, in order to secure the safety of the TBM when driving through these sections, the canopy method which was a mixed excavation method together with the conventional D&B and TBM was applied. In 4 months earlier than the eastbound, westbound main tunnel TBM was started mining on the May of 1996, unfortunately, after excavated and advanced 456 meters only, TBM was crushed and buried 100 meters long in the tunnel collapsing on December 15,1997 due to unexpected huge water inrushes with 750~800 l/sec and 18 bar water pressure. As a result, the TBM was aborted and conventional D&B was then employed in September of 1999 for the rest of westbound main tunnel.

However, the tunnel drives were severely delayed by unexpectedly difficult geology with fractured rock and massive inflows of water. In order to expedite the construction, additional working face from west portal and the vertical ventilation shaft #2 as well as the interchange station #2 for all 3 tunnels by conventional D&B were adopted. Under these circumstances, this paper would only focus on the Hsuehshan eastbound main tunnel TBM mining operation for total length of 7317 meters which starting from station 39k+512 to 32k+195.

TBM CUTTER HEAD PROFILE AND CUTTERS

The two TBMs utilized for Hsuehshan main tunnels are of full face telescope/double shielded type hard rock design with a boring diameter of 11.74m which were manufactured by WIRTH Company. The TBM's hydraulic cutter head will develop a torque of up to 36000KNm at 0.25rpm speed and the total cutter head thrust is about 50600KN in double mode and 78700KN in single mode mining operation. Total installed power is approximately 7550KW of which 4000KW is for the hydraulic cutter head drive and cutter head rotational speed is 0~4.0 rpm. The cutter head (Figure.1) is designed and manufactured considering the difficult rock conditions expected. For this reason, the head consists of a massive welded steel structure dressed with 83 back-loaded disk cutters for use in hard rock, and it is further fitted at the front with 8 radial muck buckets with teeth for use in softer formations. The teeth are cutting in back of the disk cutters. Disk cutters and teeth can be inspected and replaced from within the cutter head. The cutter saddles are an integral part of the head and are recessed to allow only part of the disk to protrude beyond the face of the head. This will prevent large pieces of rock from blocking the head in fractured formations. The flat profile of the head stabilizes the face and the shallow

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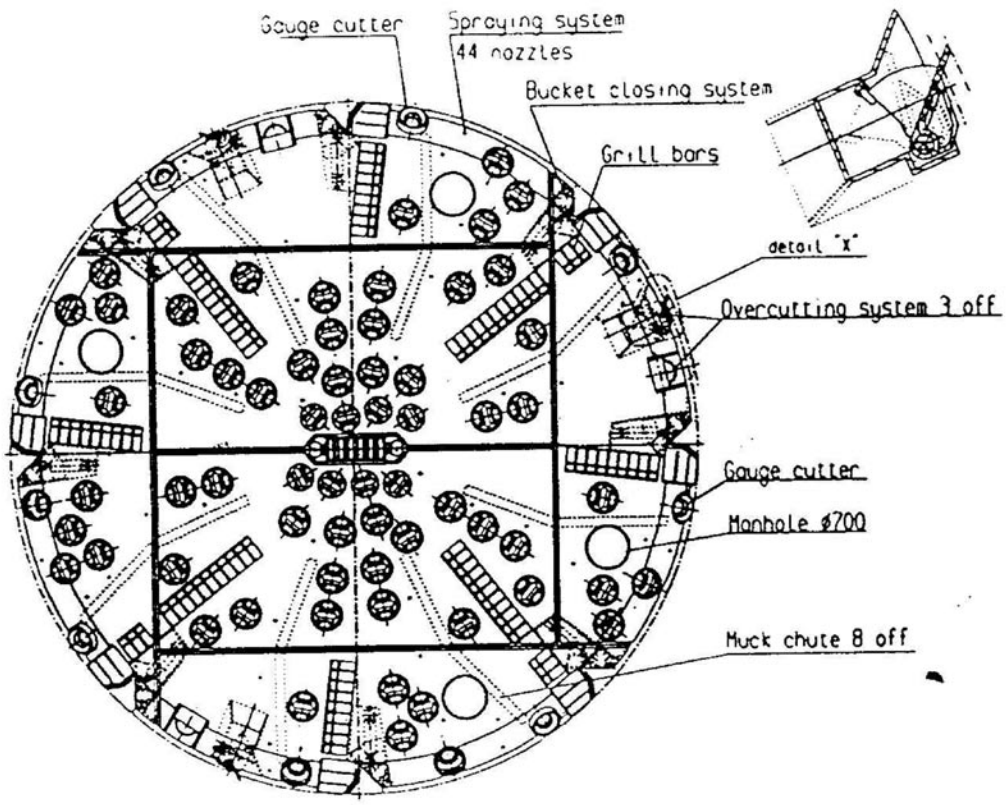

Figure.1 Cutter head profile

muck buckets and scrapers minimize the distance between the shield cutting edge and the tunnel face.

Grill bars can be inserted in the face apertures to restrict the size of the inflowing muck. The peripheral bucket openings can be opened or closed by means of hydraulically operated bucket closure doors (Figure.2).

Muck removal takes place by means of 8 scrapers and buckets at the circumference of the head, as well as the frontal radially arranged muck apertures. Guide plates inside the cutter head transfer the muck via the muck hopper to the centrally located machine conveyor. The muck hopper is at the top of the muck cylinder. In order to prevent a sudden inrush of water and mud from entering the shield when driving through faults, a hydraulically operated gate is provided to close off the muck hopper.

Cutter spacing being designed as 80mm for 60 numbers of face cutters, followed with 78, 73, 68, 64, 59, 55, 51, 47, 43, 39, and 31mm at transition area (Figure.3).

The total number of cutter and relevant specification are as follows;

1. Number of cutters: Center cutter 6 pcs, 120kgs/pc.

   Face cutter 71 pcs, 182kgs/pc.

   Gage cutter 3 pcs, 184kgs/pc. 2x135 deg, 1x90 deg, separated

   Reaming cutter 3 pcs. 2x135 deg, 1x90 deg, separated.

2. Dimension : 432 mm.
3. Bearing used : Tapered roller type.

   Dynamic load (radial): 163 KN (Timken base)

   630 KN (ISO)

4. Cutter disk ring : Material & Strength after heat treated: manufacturer's proprietary.

   Hardness: 50~59 HRC (approx.)

5. Cutter disk life guaranteed by manufacturer, if rock is homogeneous.
6. Maximum recommended individual cutter load: 220 KN min.

Rock	UCS	TS	Disk life	AM
	(MPa)	(MPa)	HR	%
Hard quartzite	1 7 0 approx.	17	175	80
Arg. Quartzite	1 4 8 approx.	15	175	80
Sand stone	7 9 approx.	8	195	70
Sand stone	4 0 approx.	4	255	50
Silt stone	3 7 approx.	5	360	25

UCS: uniaxial compressive strength.

TS : tensile strength.

AM: abrasive minerals content.

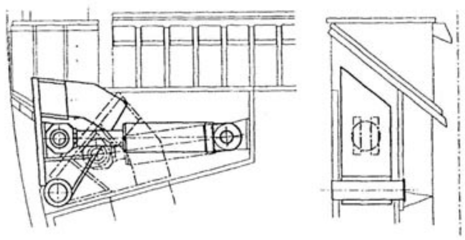

Figure.2 Bucket closing device

MAINTENANCE AND INSPECTION OF CUTTERS

Following hints and recommendations serve for the increase of lifetimes of cutting tools and, thus, for the increase of economic efficiency of tunnel boring. By means of a list, the problems of certain inspections and measures are made clear.

1. When do you have to effect a cutter head and cutter inspection?

1.1 Regularly, if possible once per shift.

1.2 Immediately, at the first signs of unnormal conditions in the cutter head area.

1.3 Immediately, when detecting steel particles in the muck.

2. What has to be checked at each inspection?

2.1 Condition of the cutting disks with regard to:

wear

chipping

stress marks

ruptures

2.2 Tight fit of all screws.

2.3 Condition of the scraper wear sheet-plates.

2.4 Condition of the bucket wear parts.

2.5 Functioning of the water nozzles.

2.6 Leakage of lubricant at the cutter support.

3. When do cutters have to be exchanged, at the latest?

3.1 Generally:

If the admissible wear of the disk has been achieved. (Check by means of template, Figure.4).

If the disk shows ground surfaces by blocking of the bearing support.

If the disk has become unusable by considerable chipping and breaks.

If oil losses can be recognized.

If loose fastening screws have damaged the contact surfaces of the axles.

3.2 Remarks:

If, on a certain cutter head part, and due to

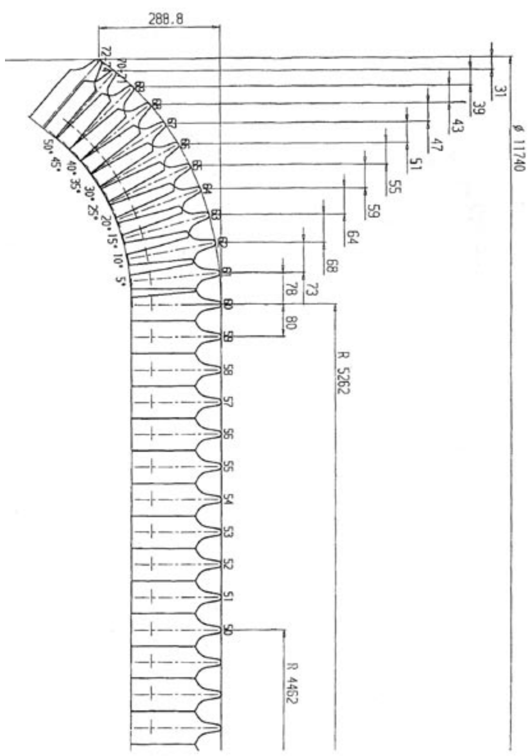

Figure.3 Cutter spacing

premature failure of individual cutters, the difference in wear between new disks and disks having been used since a rather long time already is too large, these adjacent cutters should also be exchanged (Figure.5). Partially worn cutter disks having worked on outer cutter head positions can be used again on inner positions.

When the admissible wear of a calibrating disk has been achieved, all calibrating cutters as well as cutters on pre-calibrating rows should, on principle, be exchanged. Depending on the wear of disks of those cutters which were used on pre-calibrating position they can be utilized again on inner cutter head positions.

In case of wear of individual cutters of the center, the condition of the remaining center cutters has to be inspected, as well. A partial exchange is possible, if e.g. the inner cutters with low wear are hardly set back compared to the new outer cutter. If not so, the complete center has to be exchanged.

When exchanging the outer cutter, the wear condition of the first face cutter has to be inspected.

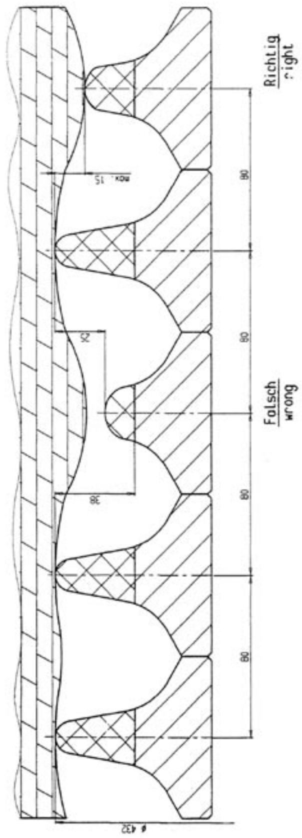

Figure.5 Allowance between new disk and worn disk

The center cutter can possibly be overstressed.

On principle, the wear limited of cutting disks can be determined by means of templates and on exchange of calibrating cutters all wear sheet plates of the scrapers have to be replaced.

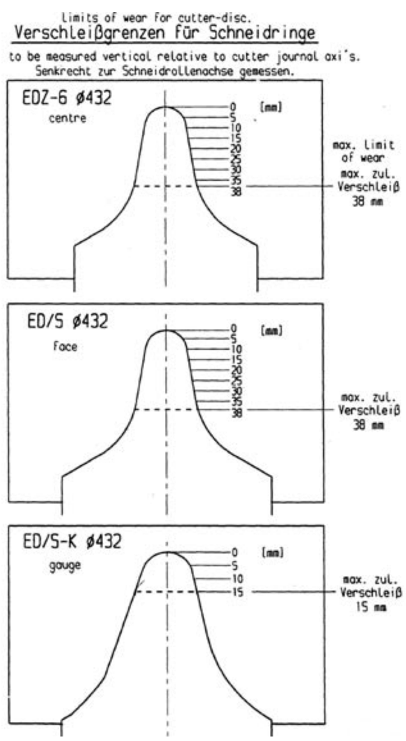

Figure.4 Template and limits of wear For cutter disk

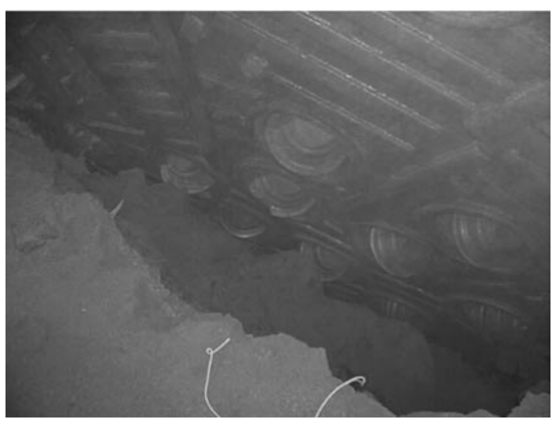

Figure.6 Fractured rock formation.

Figure.7 Cutting disk crack by strong impact.

4. What has to be considered when exchanging the cutters on the cutter head?

4.1 Evenness of the axle contact surfaces at the inserts.

4.2 Fastening of the inserts in the cutter head.

4.3 Cleanness between cutter head and inserts.

4.4 The prescribed tightening torques of all screws.

5. Repair and maintenance of cutters.

5.1 The respective assembly instructions have to be considered.

REVIEW OF CUTTERS FROM ABNORMAL DAMAGE AND IMPROVEMENT

Due to the characteristic geological conditions especially in Szeleng Sandstone formation as aforementioned, a lot of cutters were abnormally damaged in different situations.

1. At the earliest stage, in considering the TBM have to cut through strong, hard and abrasive rock formation, RSEA decided to raised the hardness of cutting disk to 59~62 HRC in between in order to minimize the consumption of both cutter cost and down time from the wear.

But unfortunately, because of intensely fractured rock formation, the mining face was not formed as a solid and stable ground to allow the cutters smoothly cut through, lots of cutters were damaged by the strong impact from collapsed big size of hard rocks which were blocked in front of cutter head during the mining. Cutting disks were started with crack and then, followed with totally broken (Figure.6, 7).

2. To conquer this situation, we were therefore, forced to reduce the hardness of cutting disk to the range of HRC 54~56. However, from the inconsistency of Szeleng Sandstone formation, when the TBM facing extremely hard, abrasive and massive rock (UCS>310Mpa, Quartzite content>90%), these cutting disks were not able to handle and speedy worn down even shown as mushroom shape, especially at the outer cutter head positions (Figure.8, 9). Certainly, the quality of raw material of the cutting ring will also be an important condition to bring the different results even though hardness is detected as the same from the surface.

3. After all, we have no choice but compromised to modify the hardness of cutting disk again to the range of HRC 56~59. In addition, also specified that, the Charpy Impact Value must higher than 0.45kg-m/cm2 in order to improve the strength at the same time try

Figure.8 Hard, abrasive and massive rock face.

Figure.9 worn cutter

Figure.10 Gauge cutter disk shape from abnormal wear

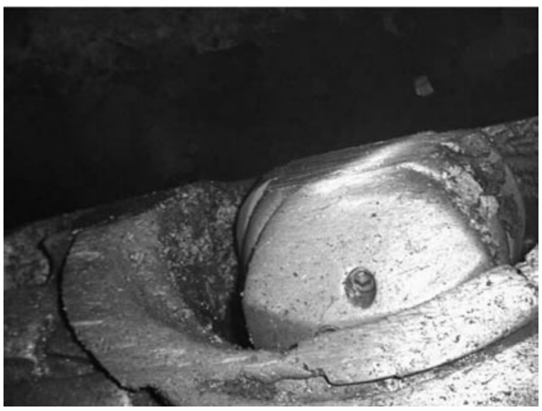

Figure.11 Seriously damaged cutter

to avoid the cutters from abnormal damage. Besides, the quality of raw material had also been putted into consideration. As a result, although the purchasing cost for the single disk is raised, but evidently reduced both the final cutter cost and down time. The most important point was avoided abnormal wear from the gauge cutters which might be caused the jam of the TBM due to the smaller tunnel diameter in the full face hard rock mining operation during the steering (Figure.10).

4. From our pass experiences, the Canopy method was a solution to secure the safety of the TBM when driving through the fault zones and the ground classified as "extremely poor conditions" (RM class VI) with expected heavy water inflows. But, it is a bit hazard to the cutters and scrapers unless precaution have been seriously taken, such as cutter inspection had been effected once per shift before start mining, detect steel particles (broken disk pieces) in the muck through the conveyor belt and the distinctive smell from leakage of lubricant from the cutters during mining…etc. Nevertheless, the situation of TBM mining operation under the Canopy method is slightly different from the full face. It is a bit difficult for TBM operator to sense the failure of cutters because of over-large top heading section even if gauge cutters or pre-gauge cutters were damaged under any circumstances. This will cause a serious damage to the cutters especially located at outer cutter head position as a chain reaction and scraper basis bodies, even will probably worn off the cutter head at the circumference (Figure.11).

But, in the full face mining operation, operator can sense abnormal situation from the gauge cutters through the increasing of the torque, thrust pressure and look up from guiding system…etc. so that he could react immediately to avoid further serious damage as aforesaid.

5. TBM penetration rate is one of the measures to secure the life time of cutters from overload. In this project, TBM penetration has been applied with 25mm/rev. according to the manufacturer's design and advice.

CUTTER WEAR-CONSUMPTION OF HSUESHAN EAST BOUND MAIN TUNNEL TBM MINING OPERATION

Hsueshan eastbound main tunnel was bored by TBM for total length of 7317 meters under a mixed excavation method together with the conventional D&B (Top heading) and full face. The total consumption of cutter was 1636 pieces containing face cutter, gauge cutter and center cutter (rebuilt cutters included). Therefore, the average cutter usage was 0.224 cutter/m as shown in Table 1.

At the stations between 36k+158 to 35k+830 of eastbound tunnel for a total length of 328 meters, it was an extremely hard, massive and abrasive ground section, the cutter usage has been increased up to 1.034 cutter/m. Blasting the rock around the circumference of cutter head by dynamite even been applied once for replace the gauge cutters. However, the cutter usage in this project for the Argillite (noted ARG) and Sandstone (noted SS) rock formation were evidently very low.

CONCLUSION

The Hsuehshan main tunnels are among the most difficult TBM projects in the world in terms of adverse geology, water inrushes, and tunnel size and tunnel length. A proper management of cutter maintenance, inspection, and repair

Table 1. Cutter wear-consumption

Date	Station	Boring distance (M)	Type of rock	Mining method	Cutter consumption (ea)				Cutter usage cutter/m
					Face	Gauge	Center	Sub. total	
Aug,1996~July,1997	39k+512~38k+858	654	Massive ARG	Full face	107	16	0	123	0.188
April,2000~Sept,2002	38k+858~36k+923	1935	Fract. QTZ(+SH)	Canopy	652	66	6	724	0.374
Sept,2002~June,2003	36k+923~36k+158	765	Fract. QTZ(+SH)	Full face	201	35	1	237	0.310
June,2003~Sept,2003	36k+158~35K+830	328	Hard ground QTZ	Full face	270	69	0	339	1.034
Sept,2003~Aug,2004	35k+830~33k+414	2416	ARG, SS	Full face	101	55	6	162	0.067
Aug,2004~Feb,2005	33k+414~32k+195	1219	ARG, SS	Canopy	35	16	0	51	0.042
		7317			1366	257	13	1636	Av.0.224

and problematic handling is one of the most crucial to the increase of economic efficiency of tunnel boring. RSEA's TBM construction team have been gone through this long period of striving under the 3D (Dirty, Difficult, Dangerous) conditions. No matter what the difficulties and problems arose in mining through this tunnel, all the working crews had never dejected but gradually acquired experiences from solving the situations.

REFERENCES

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