NUMERICAL STUDY ON THE TBM MUCKING PERFORMANCE IN THE EH PROJECT AND OPTIMIZATION OF THE SUPPORTING RIBS

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ABSTRACT

To study the cutterhead's muck transfer performance of the TBM applied in the EH project, in China, a discrete element method (DEM) based numerical model was built and the mucking process was simulated at different penetration rates and cutterhead rotational speed. It was found that the conventional straight-supporting-rib cutterhead performed well at different penetration rates and low RPMs, but the muck excessive throwing issue was serious when the RPM was higher than 10 rev/min. To overcome this problem, a new arched-supporting-rib cutterhead was proposed. The curvature radius of the arched supporting ribs is suggested between 1.25 m and 1.75 m, and the offset angle is suggested between 40° and 45°. The newly proposed arched-supporting-rib cutterhead can perform well in muck transfer at a greater RPM range of 4~13 rev/min, which allows the TBM to be excavated at low, medium, and high RPMs considering ground conditions and requirements of construction progress.

KEYWORDS

TBM, Muck transfer, Discrete element method, EDEM, Supporting rib

INTRODUCTION

As a kind of heavy professional engineering equipment, the full-section hard rock tunnel boring machine (TBM) has been widely used in the fields of hydropower, mining, highway, and railway engineering. The TBM cutterhead has key functions such as rock cutting, tunnel support, and muck transport. The muck transfer process is of vital importance for TBM tunneling because it directly affects the advancing speed, cutterhead blockage, cutter wear, and cutterhead design. The muck transfer components on a cutterhead mainly include the mucking buckets, mucking chutes, and supporting ribs. During TBM excavation, the rock muck and chips are first scooped up by the muck buckets, then pass the mucking chutes, and finally slide into a hopper through the supporting ribs. The literature is reviewed considering the three muck transfer components.

Representative studies on the muck buckets are as follows. Qi et al [1] focused on the modification and renovation of the worn muck buckets on a TB880E type TBM after its application in the Qinling tunnel and Taohuapu tunnel projects, in China. The renovated TBM was then applied in the excavation of the Zhongtianshan tunnel in Xinjiang Autonomous Region, China. Mao [2] found that the modified buckets were frequently damaged under fractured ground conditions due to the repeated strong impact of large rock blocks on the buckets. The bucket saddles and bolts were strengthened to solve this problem. Zhang [3] verified the application of a new low-alloy wear-resisting cast steel in TBM muck buckets and found that the service life can be improved by 60%. Geng et al. [4] built a numerical model of the TBM mucking process using PFC3D software to analyze the influence of bucket structure, height, and width on the cutterhead mucking performance considering the average mucking speed and passing rate. According to the aforementioned research, it is found that the muck bucket structure has been basically settled and thus the key problem lies in the bucket installation and metal wear resistance.

Representative studies on the mucking chutes and supporting ribs are as follows. Geng et al. [5-7] built the numerical models of the TBM mucking process using PFC3D and EDEM software considering the flat-face, conical-shaped, multi-stage, and corrugated cutterheads respectively. The influences of the number, length, width, and area of the mucking chutes on the mucking performance were investigated comprehensively. Xia et al [8-12] simulated the TBM mucking process using EDEM software and the results were compared with field TBM mucking tests. The influence mechanism of the structural parameters of mucking chutes on mucking performance and bucket wear was revealed, and an optimization design method for mucking chute layout was proposed. Based on the TBM mucking simulations using PFC3D software, Huo et al. [13-16] proposed a fuzzy evaluation method for the mucking performance. The influences of the mucking chutes and supporting ribs on the mucking performance were studied and the structures were optimized. Li et al. [17] simulated the TBM mucking process using the ABAQUS software to reveal the influence of supporting rib angle and cutterhead revolutions per minute (RPM) on mucking performance. According to the aforementioned research, it is found that the particle-based discrete element method (DEM) is widely used to simulate the TBM mucking process. Owing to the advantage of GPU calculation, the EDEM software seems to be more adequate to simulate the large-scale TBM mucking problem with millions of particles. As TBMs are large customized equipment, the design of the mucking components should be conducted and evaluated according to the mucking performance in specific ground conditions with different operation parameters.

In this study, the mucking process of an open-type TBM applied in Erhe (EH) project in Xinjiang Autonomous Region, China, was simulated using the EDEM software and its GPU calculation technique. The mucking performance considering the mucking rate and the muck residual quantity was evaluated when the cutterhead was rotated at different penetration rates and RPMs. To improve the mucking performance with high cutterhead RPMs, an arched supporting rib was proposed, and the structures were optimized via groups of mucking simulations. This study provides new insights and guides for the design of the cutterhead’s supporting ribs considering the mucking performance.

PROJECT OVERVIEW

Brief description of the sites

The total length of the Keshuang section tunnel in the second phase of the Xinjiang EH Water Supply Project is about 283.4 kilometers, rendering it the world's longest water supply tunnel. The project crosses the low mountains and hilly areas between the south slope of the Altay Mountain and the north slope of the East Tianshan Mountain. The landscape features high elevations in the northern regions and lower ones in the southern parts, with the east being elevated and the west lower in altitude. The overall terrain gradually decreases from northeast to southwest, with the altitude ranging from 750 to 1300 meters.

The total construction length of the bid-II section is 23.34 kilometers. As shown in Figure 1, the tunnel was first bored with a TBM from the northwest exit to the middle for 10840 m. Upon

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completion of the central 2000-meter stretch using the drill and blast (D & B) technique, the TBM was overhauled and stepped through this section and then bored the next section of 10500 m toward the southeast exit. The tunnel route's geological composition primarily consists of tuff and tuffaceous sandstone from the Carboniferous and Devonian periods, as well as intrusive granite from the Variscan period. The rocks are hard and the rock mass is intact, mostly of medium to hard grade, belonging to Class II and III surrounding rocks. It is suitable for the application of a TBM because the maximum buried depth is no more than 150 m and thus the rock burst risk is low. However, there are 10 fracture zones along the tunnel alignment and the width of fracture zones is from 4 m to 35 m. Meanwhile, the inclination angles of the fracture zones are at least 55 degrees. When the TBM excavates in the fracture zones, the rock muck amount is possibly large and the rock chips are possibly massive in size, which may cause the stuck of the TBM. As a result, it is necessary to analyze the mucking performance and verify the mucking ability of the TBM cutterhead.

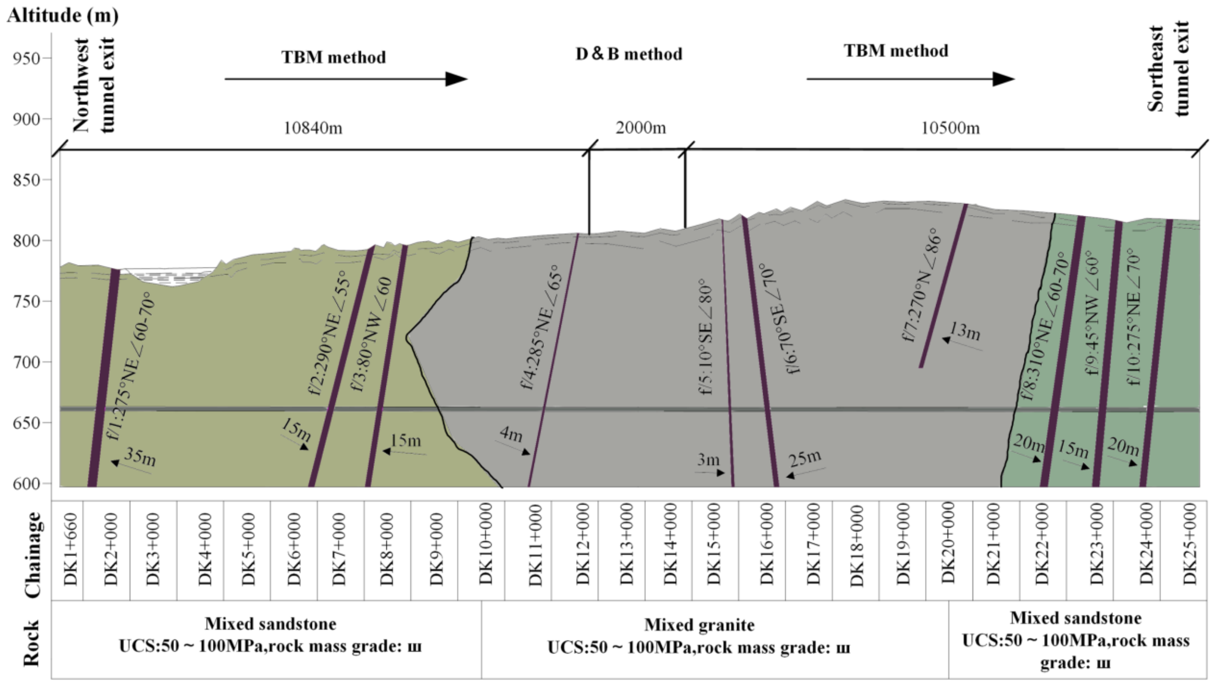

Fig. 1 - Geological profile along the tunnel alignment of bid-II section (the scale ratio of the horizontal to the vertical axis is 25:1)

Brief description of the applied TBM and field penetration data

The applied 'ZTT7030' open-type hard rock TBM was manufactured by China Railway Construction Heavy Industry (CRCHI) corporation limited. As shown in Figure 2, the total length and weight of the TBM are 220 m and 1300 t, respectively. The length and weight of the TBM host from the cutterhead to the rear support are 23.8 m and 600 t, respectively. The total installing power is approximately 4403 kW. The maximum excavation diameter is 7.03 m when new gauge cutters are equipped. A cutterhead is equipped with a total of 48 constant cross section (CCS) disc cutters, comprising 8 central cutters (i.e. 4 double disc cutters with 17 inches in diameter), 28 face cutters with 19 inches in diameter, and 12 gage cutters with 19 inches in diameter. A total of 6 mucking chutes are set on the outer circumference of the cutterhead and the mucking buckets are mounted respectively. The chips allowed to pass the mucking chutes are smaller than 250 mm in the middle axis. The cutterhead is driven by eight 350-kW motors, resulting in the cutterhead revolutions per minute (RPM) of 0~10.9 rev/min, rated torque of 4410 kN·m (at 5.5-rev/min RPM), and extricating torque of 6620 kN·m (at 0.5-rev/min RPM). The cutterhead is pushed via the main beam by 4 thrust

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cylinders of 2000 mm in stroke, resulting in the rated and maximum thrust of 23562kN and 27489 kN, respectively. The muck conveying ability of the main belt conveyer is 1000 t/h.

The field penetration data, including the torque, thrust, RPM, and penetration of the cutterhead are shown in Figure 3 when the TBM excavated in a successive excavation chainage from DK15462 to DK15488. The data were exported from the industrial computer for one time per minute. This period lasted for 500 min and the advancing distance was 26 m. During this period, the excavation was stopped 9 times, including 6 regular step changes which lasted 5 min for each, and 3 rests for regular tunnel support works which lasted 30 min for each. The time for net penetration counted for 73.8% of the total period, indicating a high machine utilization ratio. During the regular penetration, the average cutterhead thrust and torque were 11953 kN and 1678 kN·m respectively, which account for 51% and 38% of the rated thrust and torque respectively. The rock-breaking ability of the TBM was not fully exploited considering the influences of rock mass stability, cutter wear, and tunnel support speed. The cutterhead RPM was stable whose average value was 6.2 rev/min. The average penetration was 7.1 mm/rev. The field penetration data can guide the parameter setting of the mucking numerical model in the next section.

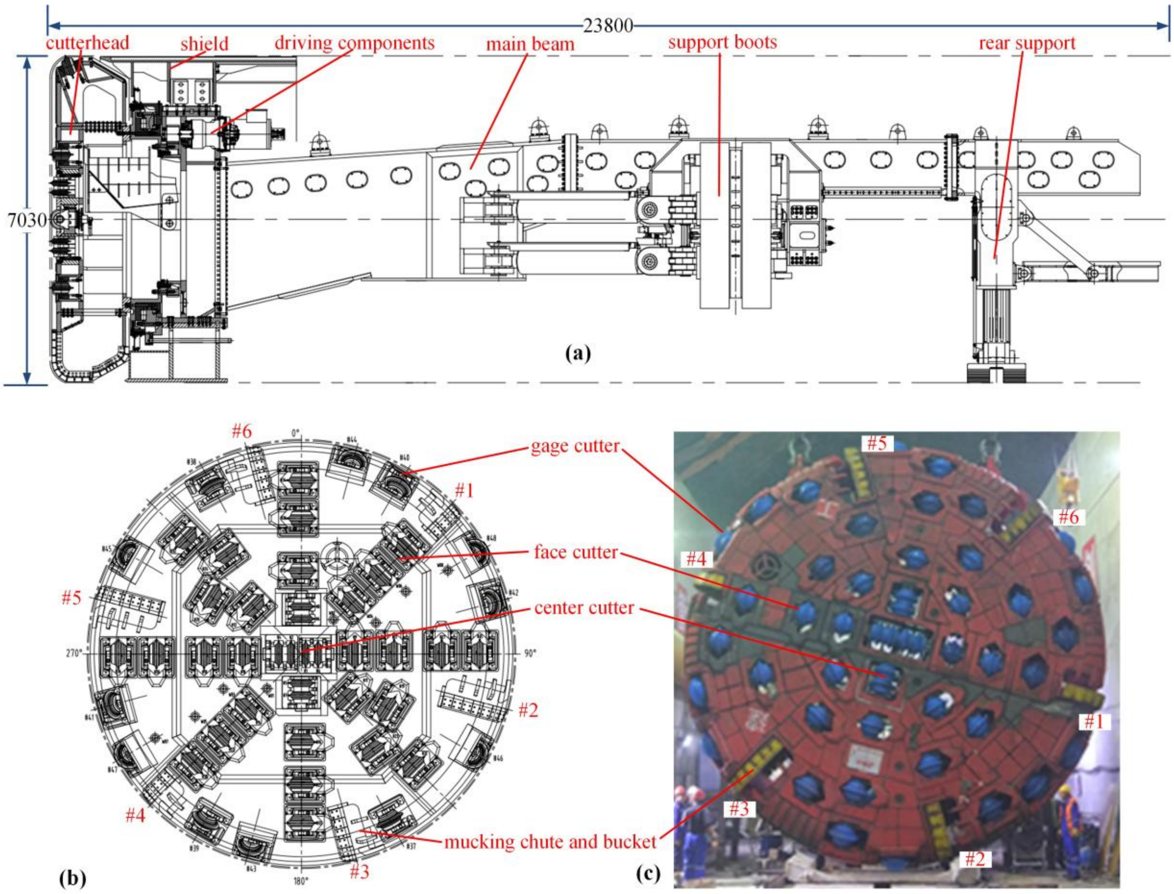

Fig. 2 - The applied ZTT7030 TBM, (a) the host machine, (b) layout of cutters and mucking chutes on the cutterhead, (c) hoisting and installation of the cutterhead on site.

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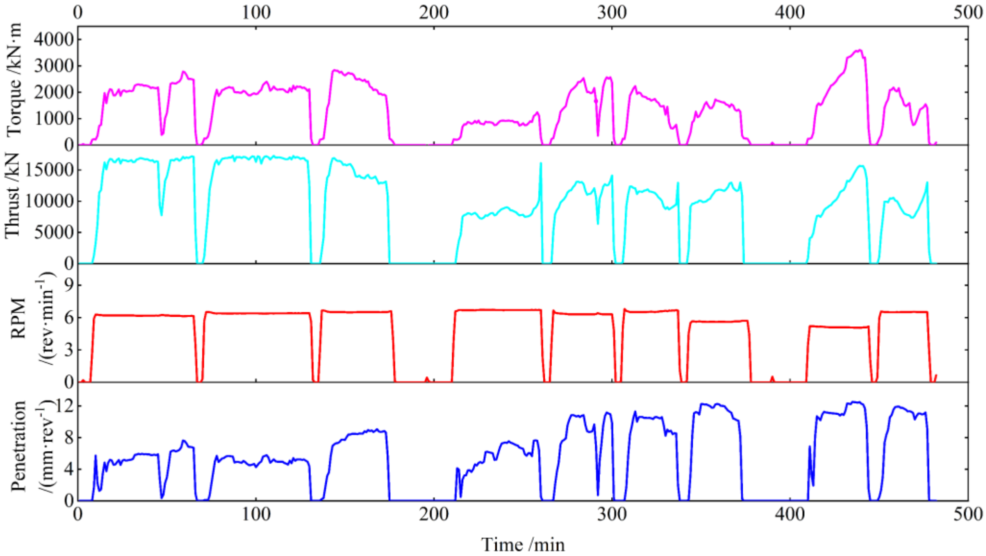

Fig. 3 - The TBM field penetration data in DK15462-15488.

NUMERICAL ANALYSIS OF THE CUTTERHEAD MUCKING PERFORMANCE

Model setup

The particle-based DEM software EDEM^{3D} was used to build the numerical model of the rock muck transfer process. According to Geng et al. [6], the rock mucking performance was not affected by the disc cutters. Thus, the cutters and their installing boxes were not modeled to improve the calculation speed. The cutterhead was modeled according to the drawing shown in Figure 2. The structure and dimension of the mucking components including the mucking chutes, mucking buckets, and supporting ribs were in accordance with the drawing. The intricate cutterhead and muck hopper were crafted in binary stereolithography (STL for short) format with Creo software and subsequently brought into EDEM^{3D} software as rigid components. The tunnel face and surrounding face are directly modeled in the EDEM^{3D} software.

According to Geng et al. [5], the simulation result of the rock mucking process is strongly affected by the dimension and shape of the rock chips. To improve the simulation accuracy, the rock chips were statistically modeled using a 3D reconstruction technology. As shown in Figure 4, a group of rock chips were randomly collected from the project site. The chips were then scanned using a 3D scanner to reconstruct the STL-format models. Next, the STL-format chips were imported into the EDEM^{3D} software and filled with particles to accomplish the particle-aggregated chip templates. During the simulation, the number of chips generated based on each template was controlled by the volume of each template as well as the cutterhead diameter, RPM, and penetration. The physical properties and contact parameters are shown in Table. 1.

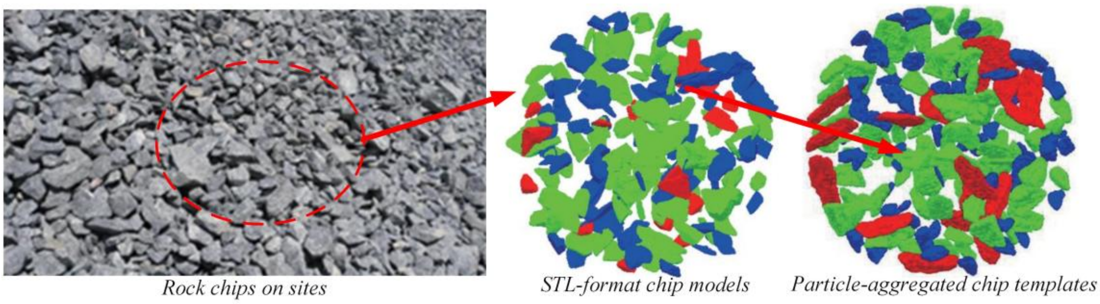

Fig. - 4 Process of the rock chip modelling.

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Tab. 1 - Model physical properties and contact parameters

Model parts		Poisson's ratio	Density/(kg·m-3)	Young's modulus/GPa
Structural elements		0.3	7850	210
Rock chips		0.25	2600	55
Contact group	**Contact model**	**Restore coefficient**	**Static friction coefficient**	**Sliding friction coefficient**
Chip-chip	Hertz- Mindlin	0.3	0.5	0.05
Steel-chip		0.5	0.4	0.03

During the EDEM simulation process, the rock debris can be set as either unbreakable or breakable, referred to as particle blocks and particle clusters respectively. Setting the rock debris as breakable particle clusters allows for the simulation of secondary breakage during the stirring and discharge processes, which more closely resembles the actual debris discharge process. However, the rock debris used in this study was sourced from a conveyor belt and had already undergone secondary breakage, thus there was no need to simulate the secondary breakage process of the debris. If the rock debris were set as breakable particle clusters, it would consume a significant amount of time in steps such as contact traversal and bond analysis, greatly increasing the computational cost. Therefore, the rock debris was set as unbreakable.

Based on the above settings, the numerical model for rock muck transfer of the TBM cutterhead is illustrated in Figure 5. The structural elements include a cutterhead body colored in grey, a muck hopper colored in yellow, and the tunnel and surrounding surfaces represented in meshes. The cutterhead body is composed of the front panel, mucking chutes and buckets, supporting ribs, the back cone, and the flange. The distance between the front surface of the cutterhead and the tunnel face is set as 145 mm, which is identical to the height of the center and face cutters. The muck hopper is composed of a funnel and a slide to collect the muck from the supporting ribs and transfer it out of the model domain in order to improve the calculation speed. The muck is generated from a particle factory that is located near the tunnel face. The muck falls to the tunnel bottom by gravity is scooped up by the mucking buckets, and then passes the mucking chutes, and then glides into the hopper via the supporting ribs. The simulation lasts for 40 s. To evaluate the mucking performance, the weight of muck at the base of the space between the cutterhead and tunnel face (M_F, kg), the weight of the muck in the cutterhead chamber (M_C, kg), and the weight of the muck transferred from the hopper (M_T, kg) were recorded every 0.1 s during the simulation. The muck passing rate (PR) can be calculated as the ratio of M_T to the weight of the generated muck (M_G, kg) in the time period from 20 s to 40 s when the mucking process is stable.

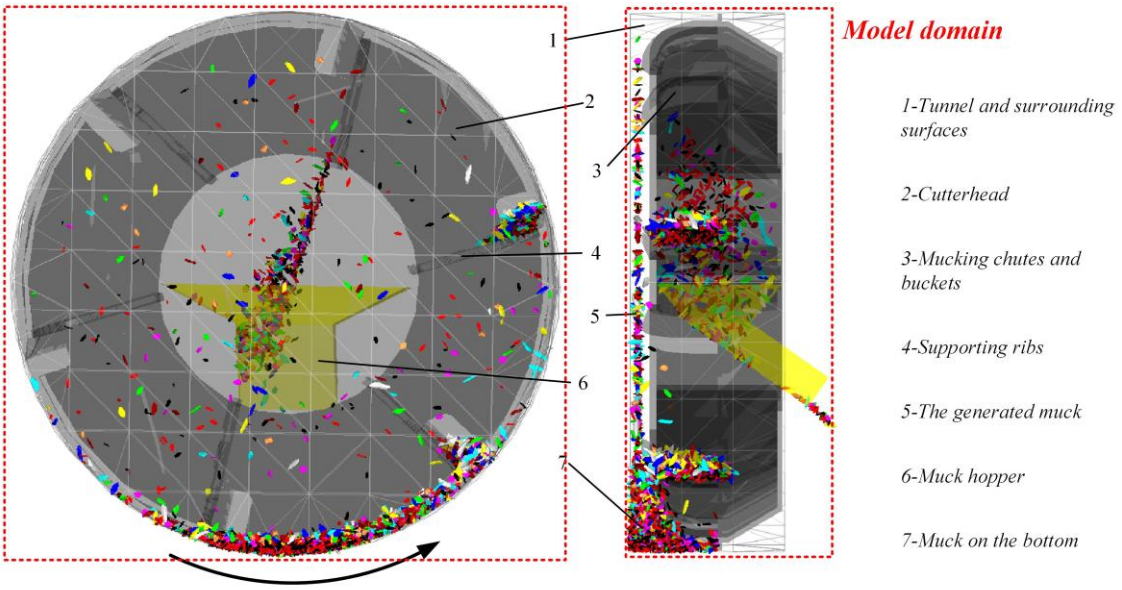

Fig. 5 - Illustration of the numerical model for rock muck transfer of the TBM cutterhead.

Influence of the penetration rate on mucking performance

According to Figure 3, the cutterhead's RPM was generally stable with an average value of 6.2 rev/min. However, the penetration rate varied from 4 mm/rev to 12 mm/rev. To examine how the penetration rate affects mucking efficiency, five simulations were conducted using the model shown in Figure 5 by setting the penetration rate as 4, 6, 8, 10, and 12 mm/rev, respectively. The cutterhead's RPM was kept at 6.2 rev/min. The mucking performance under different penetration rate is shown in Figure 6. Each figure was captured at 24.5 s when the mucking process was stable. The increase of muck generate rate from 41.4 kg/s to 124.1 kg/s can be observed from the front of the models. According to Figure 6 and Figure 7, as the penetration rate increases, the amount of the muck accumulated in the tunnel bottom (M_F) increases obviously, which may exacerbate the secondary wear of the gage cutters. Besides, the weight of the muck removed by each mucking bucket and the M_C increase with the increasing penetration rate, which may bring in additional resistance moments for the cutterhead. For each penetration rate, the fluctuation of M_F and M_C becomes stable after 15 s, indicating that the muck generation and transfer enter a dynamic balance mode. It means that the muck in the tunnel bottom and cutterhead chamber will not keep accumulating and increasing, indicating that the ability of the cutterhead to transfer muck is sufficient under the studied conditions with different penetration rates. This is also proved by Figure 7c, which shows that the muck passing rate (PR) is near 100% for different penetration rates. For each model, the fluctuation frequency of M_F and M_C is 0.63 Hz, which equals the product of the amount of mucking chute and cutterhead revolutions per minute.

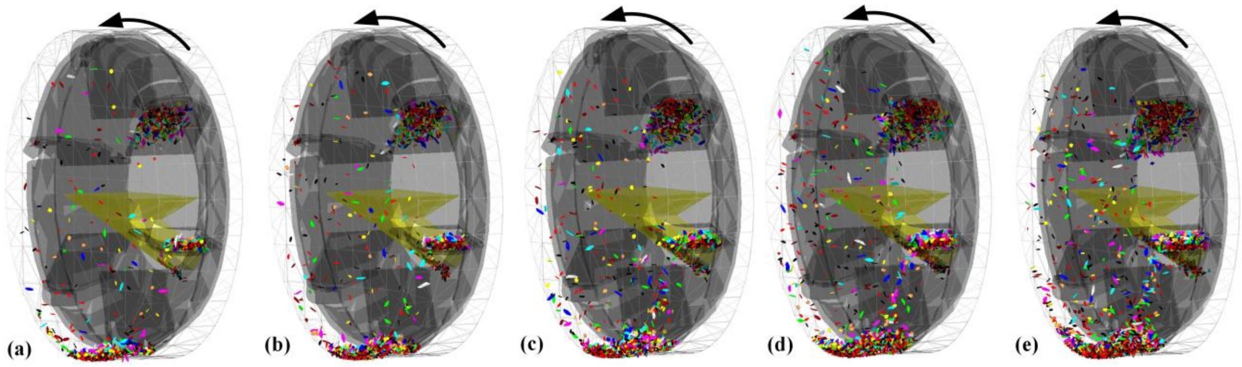

Fig. 6 - Mucking performance under different penetration rates, (a) 4mm/rev; (b) 6 mm/rev; (c) 8 mm/rev; (d) 10 mm/rev; (e) 12 mm/rev.

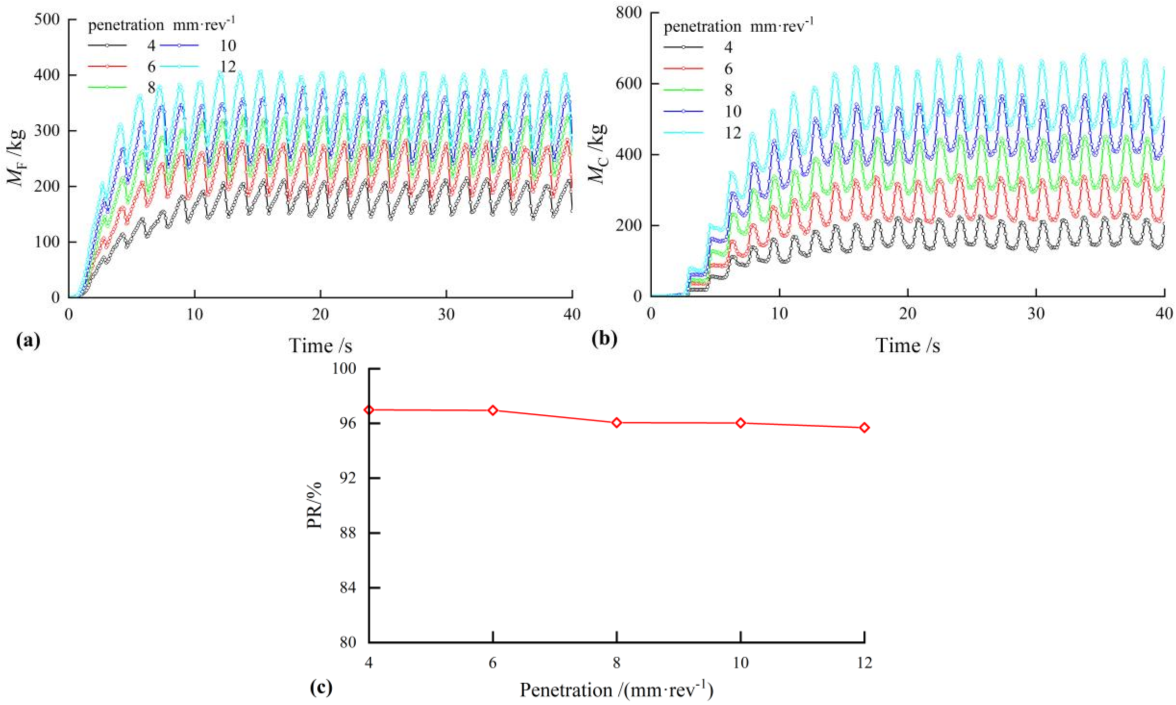

Fig. 7 - Indicators to evaluate the mucking performance under different penetration rates, (a) M_F; (b) M_C; (c) PR.

Influence of cutterhead's RPM on mucking performance

Although the cutterhead's RPM was generally stable during the given stage in Figure 3, it can be improved properly in some stable and not-so-hard ground conditions in order to increase the TBM advance rate on the premise of not serious cutter wear. To examine the impact of the cutterhead's RPM on mucking performance, four simulations were conducted using the model shown in Figure 5 by setting the RPM as 4, 7, 10, and 13 rev/min, respectively. The penetration rate was kept at 7 mm/rev. The mucking performance under different cutterhead's RPM is shown in Figure 8. Each figure was captured at 24.5 s when the mucking process was stable. The increase of muck generate rate from 70 kg/s to 227.5 kg/s can be observed from the front of the models. According to Figure 8 and Figure 9a, as the RPM increases, the amount of the muck accumulated in the tunnel bottom (M_F) is generally the same for different models. This occurs because although the muck generates rate increases with the increase of RPM, the scooping frequency of the muck buckets also increases with the increase of RPM. When the RPM is lower than 10 rev/min, the fluctuation of M_C is stable for different models after 15 s (Figure 9b), and the PR is near 100% (Figure 9c), which indicates that the muck generation and transfer can enter a dynamic balance mode. For the model with an RPM of 10 rev/min, although the PR is near 100%, the muck mainly falls on the left side of the hopper and is about to be thrown out of the hooper. For the model with an RPM of 13 rev/min, a large amount of muck remains on the mucking chutes and supporting ribs and accumulates in the cutterhead chamber. The M_C increases as the simulation progresses and its value is much larger than the other three models. Meanwhile, the PR is only about 86%, indicating the insufficient mucking ability of the cutterhead. This is because that much muck is thrown out of the hopper and keeps accumulating in the cutterhead chamber due to the high linear velocity, which can be observed in Figure 8d. It indicates that the RPM of the studied 7.03-m-diameter cutterhead should better be lower than 10 rev/min, which agrees with the designed RPM range (0~10.9 rev/min) of the TBM.

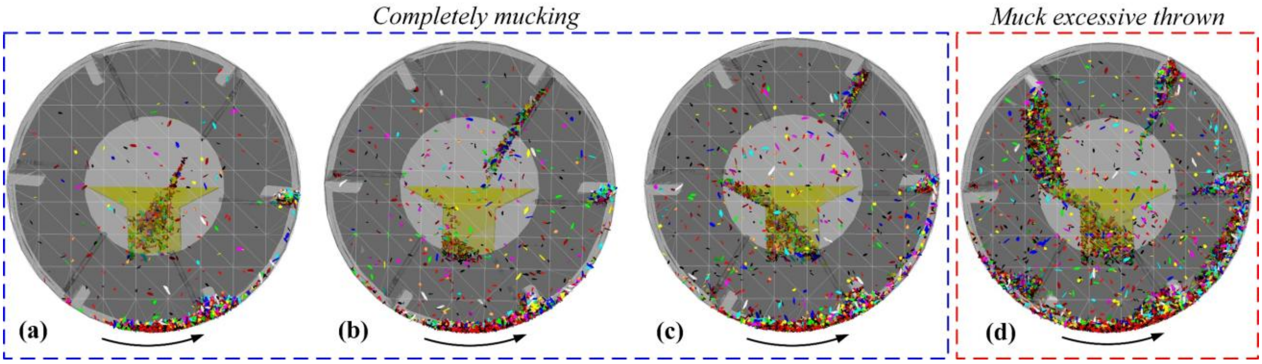

Fig. 8 - Mucking performance under different cutterhead's RPM, (a) 4 rev/min; (b) 7 rev/min; (c) 10 rev/min; (d) 13 rev/min.

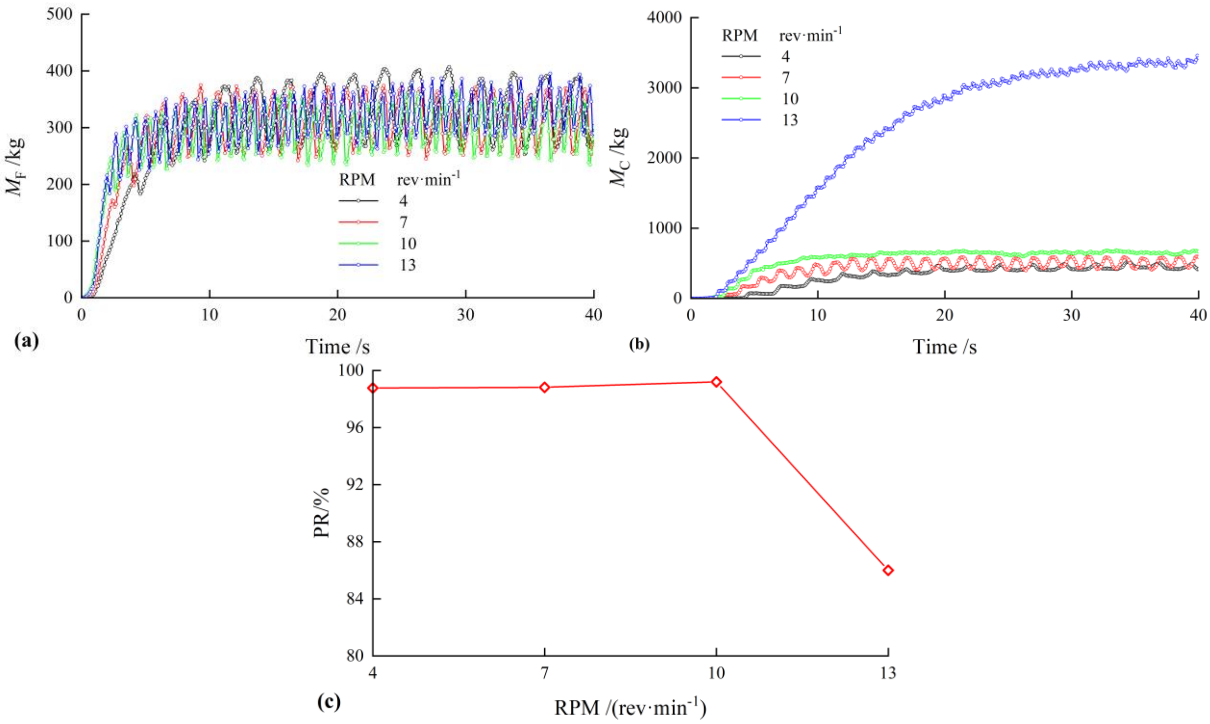

Fig. 9 - Indicators to evaluate the mucking performance under cutterhead's RPM, (a) M_F; (b) M_C; (c) PR.

DESIGN AND OPTIMIZATION OF ARCHED SUPPORTING RIBS

Based on the above analysis, the unsuitable of the straight-supporting-rib cutterhead for high RPM operation is caused by the long-distance throw of the muck due to the high linear velocity of the outer circumference of the cutterhead. In contrast, the arched-supporting-rib cutterhead may perform better which is illustrated in Figure 10. Compared with a conventional cutterhead and its cutter layout, the position angles of some cutter holes should be slightly adjusted to avoid interference. Two parameters, i.e., the offset angle α and curvature radius ρ may affect the mucking performance and thus should be carefully designed.

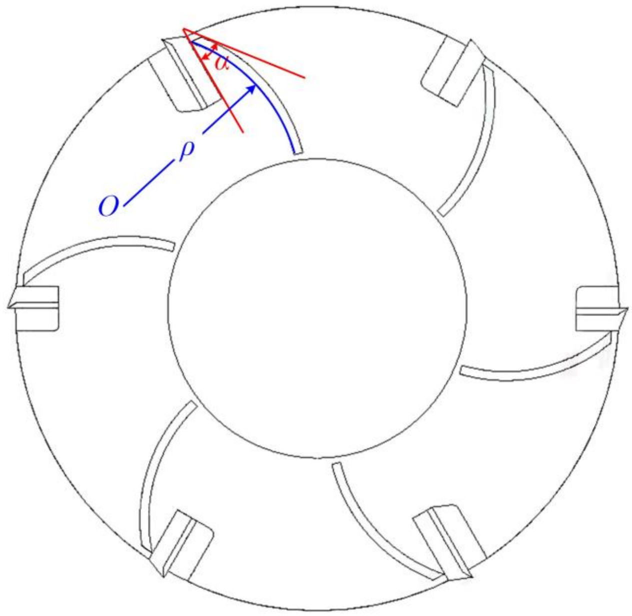

Fig. 10 - Illustration of the position of the arched supporting ribs on the TBM cutterhead.

Influence of curvature radius on mucking performance

To study the influence of ρ on the arched supporting ribs, five simulations were conducted by setting the ρ as 1.0, 1.25, 1.5, 1.75, and 2.0 m, respectively. The α, penetration rate, and RPM were set as 60°, 7 mm/rev, and 13 rev/min, respectively. The other cutterhead structure and parameters were the same as the model shown in Figure 5. The mucking performance of cutterheads with different ρ is shown in Figure 11. Each figure was captured at 30 s when the mucking process was stable. When the ρ was 1.0 m, some muck was thrown out of the hopper (excessively thrown) and fell on the convex side of the arched supporting ribs. As the cutterhead rotated, the muck fell on the concave side of the neighbouring supporting ribs and entered the next cycle. Thus, the M_C value was much higher and the PR was lower (Figure 12b) than the other models (Figure 12a) respectively. As the ρ improved, the falling position of the muck into the hopper moved right and the excessive throwing issue was mitigated. Thus, the M_C was low and the PR was almost 100%. When the ρ was 2.0 m, a little muck could not fall into the hopper (insufficient thrown) during the first 15 s due to its relatively low linear speed. However, as the mucking progressed, the muck could still fully flow into the hopper during the following cutterhead revolutions. This is why the M_C value of the 2.0-m-ρ model was relatively low but a little higher than the models with ρ of 1.25 m, 1.5 m, and 1.75 m. Meanwhile, the PR of this model can achieve almost 100%. These results indicate that the mucking performance of the arched supporting ribs is significantly affected by the curvature radius ρ. The smaller the ρ, the excessive throwing issue will be more prone to occur. The larger the ρ, the insufficient-thrown problem will be more prone to occur. For a certain α value, there exist proper ρ values with which the mucking performs well at high cutterhead RPM.

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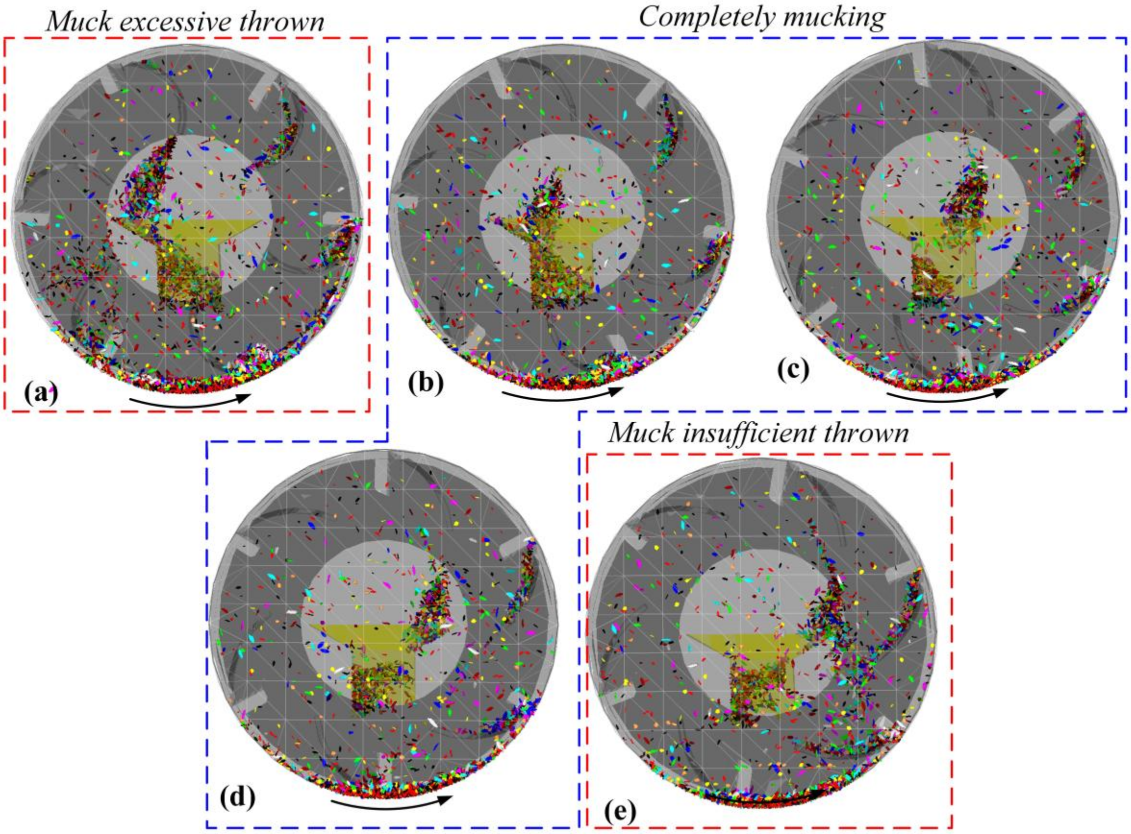

Fig. 11 - Mucking performance of cutterhead with different curvature radius of the arched supporting ribs at RPM of 13 rev/min, (a) 1 m; (b) 1.25 m; (c) 1.5 m; (d) 1.75 m; (e) 2 m.

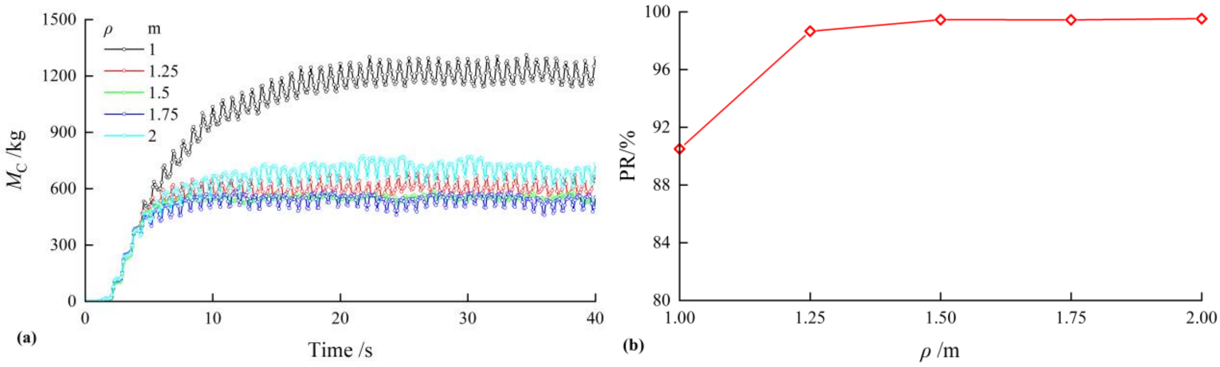

Fig. 12 - Indicators to evaluate the mucking performance of cutterhead with different curvature radius of the arched supporting ribs at RPM of 13 rev/min, (a) M_C; (b) PR.

Influence of offset angle on mucking performance

To study the influence of *α* on the arched supporting ribs, six simulations were conducted by setting the *α* as 35°, 40°, 45°, 50°, 55°, and 60°, respectively. The *ρ*, penetration rate, and RPM were set as 1.75 m, 7 mm/rev, and 13 rev/min, respectively. The other cutterhead structure and parameters were the same as the model shown in Figure 5. The mucking performance of cutterheads with different *α* is shown in Figure 13. Each figure was captured at 30 s when the mucking process was stable. When the *α* was 35°, a little muck was thrown out of the hopper, which caused muck accumulation in the cutterhead chamber and thus a high M_C value. Even so, the accumulated muck can be further transferred into the hopper during the following cutterhead revolutions. Compared with the straight-supporting-rib model shown in Figure 8d, the M_C was much lower and the PR was much higher. This indicates that the arched-supporting-rib cutterhead performed better in mucking at high RPMs. As the *α* improved, the falling position of the muck into the hopper moved right and the excessive throwing issue was mitigated. Thus, the M_C was low and the PR was almost 100%. When the *α* is 60°, the muck can fully fall into the hopper but the insufficient-thrown problem will possibly appear for models with higher *α* values. These results indicate that the mucking performance of the arched supporting ribs is significantly affected by the offset angle *α*. The smaller the *α*, the excessive throwing issue will be more prone to occur. The larger the *α*, the insufficient-thrown problem will be more prone to occur. For a certain *ρ* value, there exists a proper *α* value with which the mucking performs well at high cutterhead RPM.

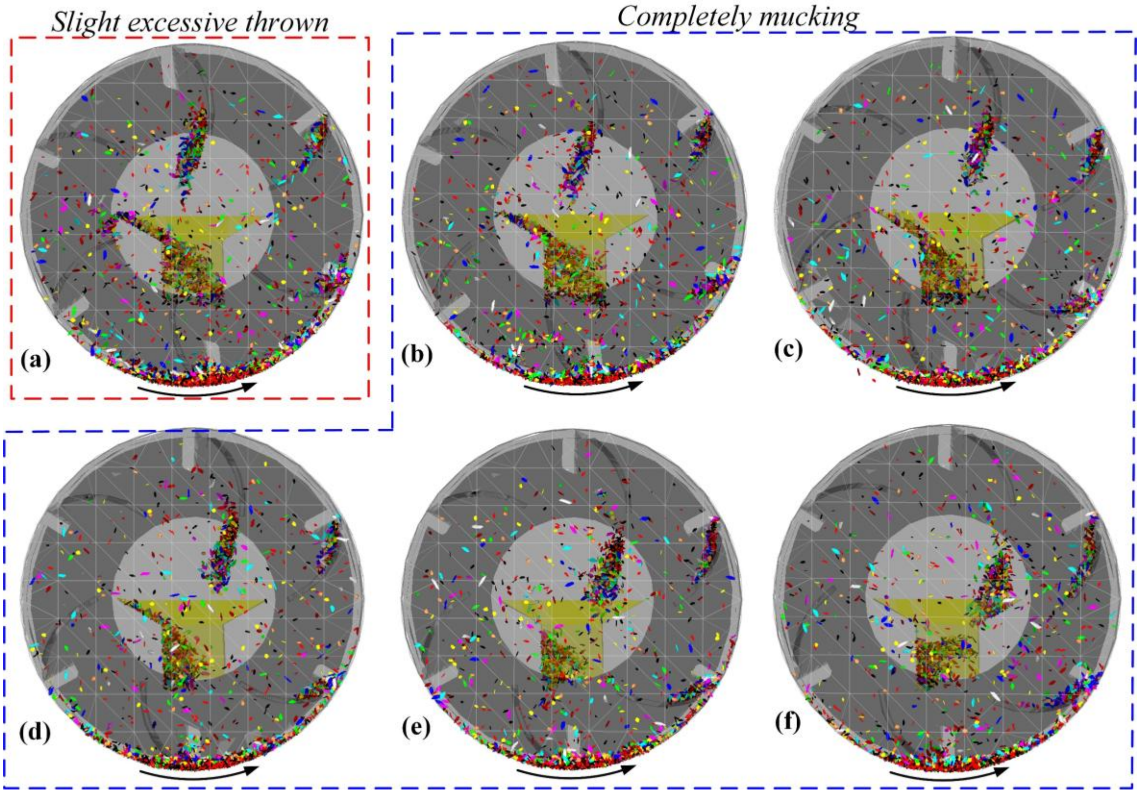

Fig. 13 - Mucking performance of cutterhead with different offset angles of the arched supporting ribs at RPM of 13 rev/min, (a) 35°; (b) 40°; (c) 45°; (d) 50°; (e) 55°; (f) 60°.

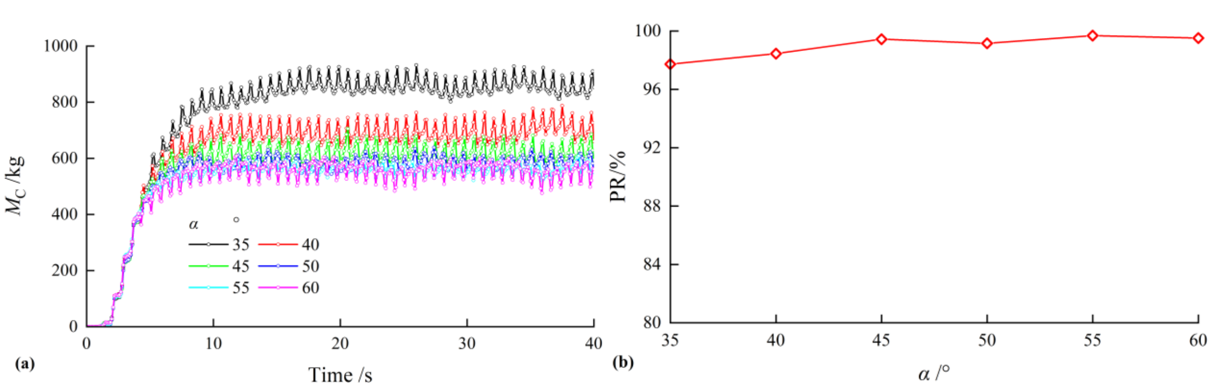

Fig. 14 - Indicators to evaluate the mucking performance of cutterhead with different offset angles of the arched supporting ribs at RPM of 13 rev/min, (a) M_C; (b) PR.

Mucking performance of arched-supporting-rib cutterhead at low RPMs

The simulations in the above two sections were conducted at a high RPM of 13 rev/min. However, the insufficient-thrown problem of muck will possibly occur at low RPMs for the arched-supporting-rib cutterhead. As a result, four simulations were conducted using the models shown in Figure 13 (b)~(e) by setting the RPM as 4 rev/min. The penetration rate was the same with previous models of 7 mm/rev. The mucking performance of cutterheads with different α is shown in Figure 15. Each figure was captured at 30 s when the mucking process was stable. When the α was 40°, the muck fully fell into the hopper, resulting in a low M_C value and almost 100% PR. When the α was 45°, an insufficient-thrown problem began to occur in the beginning, which caused slight muck accumulation in the cutterhead chamber and thus a higher M_C value than the 40°-α model. Even so, the accumulated muck can be further transferred into the hopper during the following cutterhead revolutions. Thus, the PR is still almost 100%. For the models with α of 50° and 55°, the muck insufficient-thrown problem was very obvious. The M_C kept increasing during the simulation, indicating that the muck kept accumulating in the cutterhead chamfer since the muck transfer and generation cannot enter a dynamic balance state. Thus, the PR was much reduced especially for the 55°-α model the PR was 0, indicating no muck transferred outside. Based on the above analysis, the ρ is suggested between 1.25 m and 1.75 m, and the α is suggested between 40° and 45°. Using these designs, the studied 7.03-m-diameter cutterhead with arched supporting ribs can perform well in muck transfer at an RPM range of 4~13 rev/min.

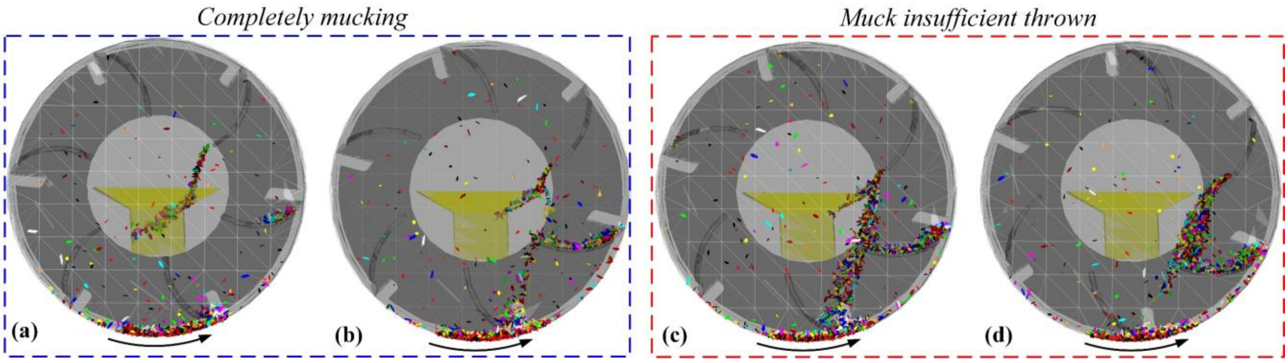

Fig. 15 - Mucking performance of cutterhead with different offset angles of the arched supporting ribs at RPM of 4 rev/min, (a) 40°; (b) 45°; (c) 50°; (d) 55°.

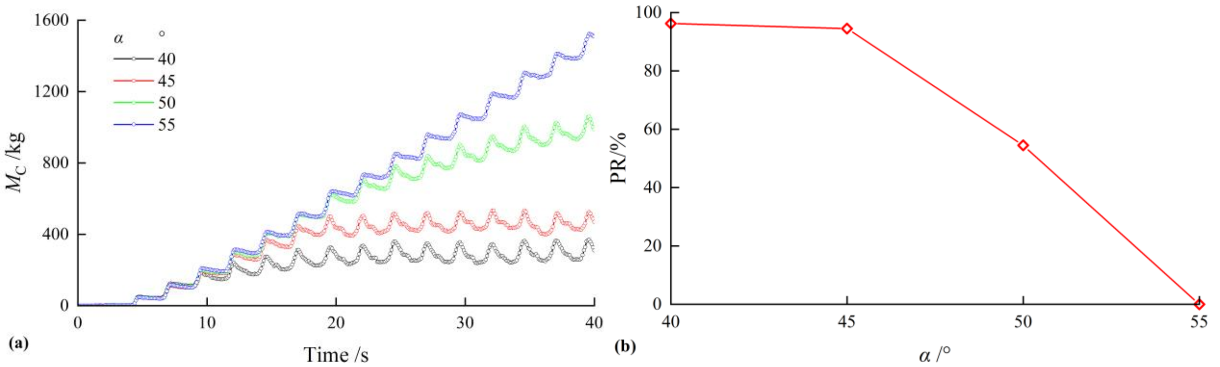

Fig. 16 - Indicators to evaluate the mucking performance of cutterhead with different offset angles of the arched supporting ribs at RPM of 4 rev/min, (a) M_C; (b) PR.

CONCLUSIONS

In this study, the cutterhead's muck transfer performance of the TBM applied in the EH project, in China, was investigated using a DEM numerical model, and a new arched supporting rib was proposed and designed. For the studied 7.03-m-diameter TBM, the conventional straight-supporting-rib cutterhead performed well at different penetration rates and low RPMs, but the muck excessive throwing issue was serious when the RPM was higher than 10 rev/min. As a comparison, the newly proposed arched-supporting-rib cutterhead can perform well at a greater RPM range of 4~13 rev/min if the supporting ribs are specifically designed. The curvature radius of the arched supporting ribs is suggested between 1.25 m and 1.75 m, and the offset angle is suggested between 40° and 45°. The increase of the curvature radius and offset angle can mitigate the muck excessive throwing issue but aggregate the muck insufficient-thrown problem.

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