

Research on Road Construction and Maintenance Technology of Open-Pit Mines

Qiqi Zhu *, Lei Kong

China Coal No.71 Engineering Company Limited, Suzhou Anhui, 234000, China

* Corresponding author: Qiqi Zhu (Email: 705674634@qq.com)

Abstract: As an important infrastructure for mine production and transportation, the construction quality and maintenance level of open-pit mine roads directly affect the efficiency, safety and economic benefits of mine transportation. This paper systematically analyzes the characteristics and classification of open-pit mine roads, discusses the key technologies of road construction, including subgrade treatment, pavement structure design, drainage system setting, etc., and elaborates the technical points and management measures of road maintenance. At the same time, combined with the development trend of modern technology, the application prospect of intelligent technology in mine road management was discussed. The research shows that scientific and reasonable road construction and maintenance technology can significantly improve the service life of roads, reduce transportation costs, and improve the overall operation efficiency of mines.

Keywords: Open-pit Mines; Road Construction; Road Maintenance; Drainage System; Intelligent Management.

1. Introduction

The open-pit mine road is an important link connecting key production areas such as the stope, waste dump, and crushing station, undertaking the heavy responsibility of transporting ore and stripping materials [1]. With the continuous expansion of open-pit mining scale in China, the transportation pressure of mine roads is increasing day by day, and the importance of road construction and maintenance technology has become more and more prominent. According to statistics, the infrastructure investment of the mine transportation system accounts for about 60% of the total infrastructure investment, and the transportation operation cost accounts for about 30%-40% of the ore mining cost. Therefore, optimizing road construction technology and improving the maintenance management system are of great significance for reducing mine production costs and improving economic benefits [2].

Currently, open-pit mine roads in China generally suffer from problems such as poor evenness, severe dust generation, and insufficient maintenance. These issues not only increase vehicle wear and fuel consumption but also pose threats to driving safety. In response to these challenges, this paper systematically studies the key issues of open-pit mine road construction and maintenance from the two dimensions of technology and management, providing scientific references for mining enterprises.

2. Characteristics and Classification of Open-pit Mine Roads

2.1. Characteristics of Open-pit Mine Roads

Open-pit mine roads differ significantly from ordinary highways: first, they have complex cross-sectional shapes, numerous turns, and steep slopes; second, they bear frequent rolling by heavy-duty mining trucks, subject to large loads; third, their service life is relatively short and needs continuous adjustment with the advancement of mining; fourth, they are exposed to harsh environmental conditions, prone to impacts from rainwater, dust, etc.[3-4]. These characteristics

determine that mine roads must meet higher technical requirements in design and construction.

2.2. Classification of Open-pit Mine Roads

According to their usage functions and stability, open-pit mine roads can be classified into the following categories [5-9]:

1. Fixed roads: Backbone roads connecting major production areas (such as stopes, waste dumps, and crushing stations), with high usage frequency and long service life. This type of road has the highest requirements for smoothness and load-bearing capacity.

2. Semi-fixed roads: They remain relatively stable for a certain period of time and are mainly used to connect fixed roads and temporary mining areas. They will be gradually adjusted as mining progresses.

3. Mobile road: A temporary and simple road that constantly adjusts its position as the mining face moves, usually serving the current mining area.

4. Temporary roads: Short-term use roads built for special needs (such as emergency rescue and temporary mining), with the shortest service life.

In addition, according to their functions, mine roads can also be classified into end side roads (connecting the waste dump and the crushing station), slope roads (connecting the upper and lower mining and stripping platforms), and mining and stripping platform roads (temporary roads beside electric shovels). Different types of roads have differences in construction standards and maintenance requirements, and need to be dealt with specifically.

3. Open-pit Mine Road Construction Technology

3.1. Road Alignment and Design

Road alignment is the primary step in construction. Generally, the "zero point method" [10] is adopted: According to the proposed route and direction, a certain longitudinal slope is used. Along the contour lines of the terrain or the contour lines of the steps within the mining area, the points

where the filling and excavation height of the road centerline is equal to zero are found. Then, these zero points are connected in a line, and the horizontal and longitudinal sections of this line are adjusted to determine the exit positions. In deep concave open-pit mines, the determination of the line position should be carried out from top to bottom. Based on the data provided by the mining design, such as the step height, the width of the transportation platform, the slope Angle at the end of step mining, and the longitudinal slope of the road, the calculation and design should be conducted section by section.

The following parameters should be given priority consideration in road design:

The longitudinal slope should be controlled below 8%, and in special sections, it should not exceed 6% to 7%

The radius of the horizontal curve shall not be less than 25m, and in difficult sections, it shall not be less than 15m (speed limit signs need to be set up).

The cross slope is set at 2.4%-3.4% to facilitate drainage

The minimum line of sight meets the requirements for safe driving

3.2. Subgrade Construction Technology

The subgrade is the foundation for road load-bearing, and its quality directly affects the service life of the pavement. When constructing the roadbed of open-pit mines, the following key points should be noted:

1. Material selection: Priority should be given to using discarded relatively hard yellow sandstone for the roadbed, with a thickness of no less than 2 meters. For sections with soft soil, materials such as crushed stones and gravel can be used for replacement and filling.

2. Compaction process: Large vibratory rollers are used for layer-based compaction, with each layer not exceeding 30cm in thickness, and the compaction degree meets the design requirements. The use of modern large vibratory rollers in combination with leveling machines can significantly improve the compaction effect.

3. Special treatment: For weak foundations with high moisture content, methods such as drainage consolidation and adding curing agents can be adopted to improve soil quality.

4. Slope stability: In the excavation section, slope stability should be taken into account, and a rockfall platform (with a width of no less than 1m) should be set up to prevent rockfalls.

3.3. Pavement Structure Design

According to the usage requirements and material supply conditions, there are mainly the following types of road surfaces in open-pit mines:

1. Compacted gravel pavement: It has low cost and is easy to construct, but it has poor flatness, causes severe dust, and requires frequent maintenance. The performance can be improved by adding a wear-resistant layer (such as sunflower seed stone, clay stone nitrate, etc.).

2. Crushed stone pavement: It is paved with graded crushed stones, which have better strength and durability than mud-bound crushed stones. The recommended structure is: 30cm thick crushed stone base layer +15cm thick graded crushed stone surface layer.

3. Cement concrete pavement [11]: It features high strength and good durability, but it is costly and has a long construction period. It is suitable for fixed roads with heavy traffic.

4. Instant formed pavement using local materials: It can be quickly constructed by using the existing materials in the

mining area, with low cost but average performance, and is suitable for temporary roads.

Pavement design should follow the principle of "adapting measures to local conditions and economic rationality", and be comprehensively determined in combination with traffic volume, service life and material supply conditions.

3.4. Drainage System Design

A well-developed drainage system is the key to ensuring the durability of roads. The key points of road drainage design for open-pit mines include:

1. Road surface drainage [12]: Water is drained to the side ditch through the cross slope of the road arch (2.4%-3.4%), with the drainage length controlled within 500 meters, or an outlet is set up.

2. Side ditches and water interception ditches: Side ditches are set up on both sides of the road, and water interception ditches are set up above the top of the slope to intercept water from the slope surface. The longitudinal slope at the bottom of the ditch shall not be less than 0.5%, and the cross-sectional dimensions shall be determined based on the calculation of the catchment area.

3. Special treatment: For sections with severe water seepage, the buried pipe drainage method can be adopted to reduce the maintenance frequency.

4. Flood control coordination: The road drainage system should be designed uniformly with the flood control of the mining area to avoid mutual interference.

3.5. Safety Facility Setup

To ensure driving safety, the following safety facilities need to be set up on open-pit mine roads:

1. Earth retaining wall: Located on one side of the airport road, with a top width of 0.5-1.0 meters and a height of 1.2-1.5 meters, isolation earth retaining walls are set up for two-lane sections in dangerous areas.

2. Reverse slope setting: At turns, set the outer side to be higher (2%-6%) and the inner side to be wider (0.4-4.2m) to enhance driving stability.

3. Visual guidance facilities: Reflective signs and contour markers are set up on dangerous sections such as sharp curves and steep slopes to improve night driving conditions.

4. Speed reduction facilities: Speed bumps or vibration markings should be set up at the end of long downhill slopes, intersections and other locations to control the vehicle speed.

4. Open-pit Mine Road Maintenance Technology

4.1. Daily Maintenance Contents

Road maintenance lies in keeping the subgrade, pavement and structures in good condition. The specific tasks include:

1. Roadbed maintenance: Timely repair cracks and settlement, keep drainage unobstructed, and clear the silt in the side ditches.

2. Road maintenance:

Remove scattered debris from the road surface and fill potholes (the depth of ruts on main roads should be no more than 50mm, and for temporary roads, no more than 100mm).

Fine-grained crushed stones or coarse-grained sand are scattered on gravel roads for anti-slip purposes [13]

- Prevent road icing in winter (use sodium chloride and calcium chloride water solutions)

3. Maintenance of structures: Inspect the stability of

retaining walls, slopes, etc., and promptly repair damaged areas.

4.2. Curing Classification and Cycle

According to the scope and depth of maintenance, the maintenance of mine roads can be classified as:

1. Minor repairs: Routine maintenance, including emergency repairs of the roadbed and pavement and environmental cleaning, etc. [14], carried out as needed.

2. Medium repair: Periodic maintenance, including restoring worn road surfaces, reinforcing shoulders, and organizing drainage systems, etc., is generally carried out once every quarter.

3. Major repair: Comprehensive restorative maintenance, including roadbed reinforcement, pavement renovation, etc., is carried out every 1 to 2 years depending on the road condition.

The maintenance cycle should be dynamically adjusted based on the type of road, traffic volume and usage conditions, and a maintenance mechanism of "prevention first and combination of prevention and treatment" should be established.

4.3. Dust-proof Technology

Dust pollution in open-pit mines is severe (the dust content in the air can reach 600-900mg/m³), which not only endangers health but also accelerates the wear and tear of equipment. The main dust prevention measures include:

1. Dust suppression by sprinkling water: Use a water sprinkler truck to sprinkle water regularly to keep the road surface moist but not excessive (to avoid mud).

2. Chemical dust suppression: The road surface is treated with water-absorbing salts (such as calcium chloride) and organic binding materials (such as emulsified asphalt) for long-lasting dust suppression.

3. Road hardening: Lay cement concrete or asphalt crushed stone roads on sections with severe dust to fundamentally reduce dust sources.

4.4. Seasonal Maintenance Priorities

The focus of road maintenance varies in different seasons:

1. Rainy season: Strengthen the maintenance of the drainage system to prevent water from seeping in. Repair the water-damaged sections in a timely manner; Stock up on emergency repair supplies.

2. Winter: Prevent road icing; Stock anti-slip materials; Reduce the frequency of watering to avoid freezing.

3. Windy season: Increase the frequency of watering to control dust. Reinforce vulnerable facilities such as temporary signboards.

5. Modern Technology and Intelligent Applications

5.1. Mechanized Construction Technology

The application of modern large-scale construction machinery has significantly improved the quality and efficiency of road construction:

1. Bulldozer construction method [15]: This includes the parallel push method, the downward push groove method, etc., which can reduce the loss of roadbed materials and improve work efficiency.

2. Intelligent compaction technology: By adopting GPS positioning and automatic control of the roller, intelligent

monitoring of the compaction process is achieved to ensure uniform compaction.

3. Automatic road leveling system: Laser or GPS guides the road leveling machine to operate, improving the accuracy of road surface leveling.

5.2. Intelligent Monitoring and Management

Intelligent technology provides new means for the management of mine roads:

1. Computer vision technology: Road extraction algorithms based on deep learning (such as FCN, UNet, PSPNet, etc.) can automatically identify road boundaries and diseases, improving inspection efficiency.

2. Unmanned driving technology: Through high-precision maps and positioning, autonomous driving of mining trucks is achieved, reducing the damage to roads caused by human factors.

3. Intelligent dispatching system: Optimize vehicle operation routes, balance road loads, and extend service life.

4. Internet of Things Monitoring: Deploy sensors on key sections to monitor parameters such as the stability of the roadbed and the smoothness of the pavement in real time.

6. Economic Benefit Analysis

Scientific road construction and maintenance can bring significant economic benefits:

1. Reduced transportation costs: Well-maintained roads can lower transportation costs by 24%, reduce fuel consumption by 29%, and extend tire life by 40%.

2. Reduced equipment maintenance costs: A smooth road surface reduces vehicle vibration, lowers the failure rate, and maintenance costs can be reduced by 20% to 30%.

3. Enhanced production efficiency: The vehicle speed has increased by 31%, and the transportation efficiency has risen by 45%. Under the same conditions, the output can be increased.

4. Comprehensive benefits: After a certain open-pit mine implemented standardized maintenance, it saved over 5 million yuan in transportation costs annually, with an investment payback period of less than one year.

7. Conclusion and Prospects

The construction and maintenance of open-pit mine roads is a systematic project, which requires strict control over each link from design, construction to maintenance. Research shows that:

1. Scientific alignment, reasonable material selection and standardized construction are the basis for ensuring road quality. Modern mechanized construction technology can significantly improve work efficiency.

2. Establishing a maintenance system that emphasizes "prevention first and combination of prevention and control", implementing hierarchical maintenance, and focusing on drainage and dust prevention can effectively extend the service life of roads.

3. The application of intelligent technology provides a new means for road management, which is the future development direction.

4. Good road conditions can reduce transportation costs by more than 20%, improve production efficiency by more than 30%, and achieve significant economic benefits.

Future research can focus on aspects such as intelligent maintenance technology, new pavement materials, and low-

carbon construction techniques to promote the continuous progress of open-pit mine road technology. Meanwhile, it is suggested that the industry's competent authorities improve relevant standards and norms to provide technical guidance for enterprises.

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