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# Analysis of Rib Spalling Issues and Prevention Measures in Railway Tunnel Construction

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## Abstract

The phenomenon of rib spalling in railway tunnel construction referred to the occurrence of spalling in the surrounding rock during tunnel excavation. This was caused by complex geological conditions and engineering technical factors. Rib spalling not only led to the destruction and collapse of the surrounding rock in railway tunnels but also severely affected the stability and bearing capacity of the tunnel structure, which impacted the construction safety and operation of the railway tunnel. In this paper, through the study of the problem of rib spalling, the cause and harm of its occurrence were discussed, and the corresponding prevention measures were put forward. According to different geological conditions and engineering requirements, measures such as strengthening support, pre-treating surrounding rock and optimizing construction method could be taken to reduce the occurrence of rib spalling. In the end, the prospect of the prevention and control of the rib spalling in tunnel construction was put forward. Therefore, through an in-depth study of the causes and hazards of the rib spalling and taking reasonable preventive measures, the occurrence of rib spalling can be effectively reduced, and the safety and reliability of railway tunnel construction can be improved.

## Keywords

Railway Tunnel, Rib Spalling Issues, Prevention Measures

## 1. Introduction

The construction of railway tunnels is of great significance for modern transportation and urban development. After tunnel excavation, for some hard surrounding rocks with good rock quality, the deformation caused by excavation is small and can tend to stabilize in a short period of time. That is, hard surrounding rocks have a certain degree of self stabilization ability, which is conducive to tunnel construction. However, in complex geological environments, the deformation mechanism of surrounding rocks is diverse, especially for complex surrounding rocks, which may be very fragmented, have poor integrity, low strength, developed structural planes, weak self stabilization ability, and are easily affected by external environmental interference. Such railway tunnels are highly prone to sheet wall disasters after excavation. The phenomenon of fragmentation refers to the occurrence of local collapse, fracture, or peeling of surrounding rock during railway tunnel construction due to complex geological conditions, rock mass fractures, or engineering technical factors. If the excavation method and support measures are not selected properly, there is a risk of overall instability of the surrounding rock. Once the surrounding rock becomes unstable, it will inevitably cause a series of tunnel engineering accidents, which will affect the construction progress and, in severe cases, pose a threat to the personal safety of construction personnel [1].

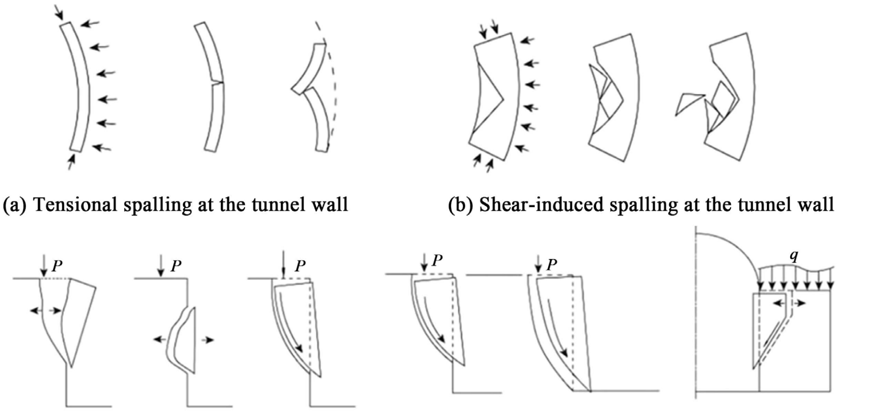
Therefore, this article focuses on analyzing the causes of the problem of rock mass fragmentation, including unstable geological structures, fractured rock structures, harsh hydrogeological conditions, and construction technology factors; At the same time, we will explore the hazards of rock mass damage, structural instability, and possible casualties and equipment damage caused by debris on tunnel railway engineering; Finally, effective prevention and control measures are proposed for the possible occurrence of debris problems during railway tunnel construction, including reinforcement and support, pre-treatment of surrounding rock, and optimization of blasting [2] [3].

Further emphasize the importance of tunnel construction monitoring and early warning systems, as well as the ability to respond promptly to debris incidents, such as breaking parameters and reasonable drainage. By conducting in-depth research on the problem of debris and its prevention measures, the occurrence of debris can be effectively prevented, which can improve the safety, stability, and reliability of tunnel engineering and provide a scientific basis and technical guidance for railway tunnel construction.

## 2. Basic Characteristics of Rib Spalling Disasters

### 2.1. Basic Forms of Rib Spalling in Railway Tunnel Sidewalls

Before the excavation of railway tunnels, the rock mass of the side walls is in a stable state of triaxial stress. After tunnel excavation, the lateral horizontal stress on the rock mass of the side wall is relieved and becomes a biaxial stress state, significantly reducing its compressive strength. At the same time, the stress on the surrounding rock of the railway tunnel is redistributed, resulting in stress concentration around it. The stress on the rock mass of the side wall increases, and when the damage to its primary cracks under the clamping effect of the top and bottom plates accumulates to a certain amount, it occurs as a shear failure. Different professional fields have different definitions and failure modes for rock mass shear walls. Tong *et al.* believe that shear walls are progressive flaking or flaking of high stress hard brittle rock masses, which can be divided into tension type plate cracking shear walls and shear type wedge-shaped shear walls, as shown in Figures 1 (a) and (b) [4]. In the mining field, it is believed that the phenomenon of detachment of the coal wall or roadway sidewall under the action of mining pressure, including tensile and shear failure, is referred to as sheet wall, as shown in **Figure 1(c)** and **Figure 1(d)**. In practical engineering, in addition to a single blade, there are also composite blades with both tension and shear, as shown in **Figure 1(e)** [5] [6].




(a) Tensional spalling at the tunnel wall (b) Shear-induced spalling at the tunnel wall

(c) Tensile cracking spalling at the coal wall (d) Shear-induced spalling at the coal wall (e) Tensile-slip spalling at the tunnel wall

Figure 1. Different spalling modes of surrounding rock in underground chambers.

## 2.2. Typical Characteristics of Rib Spalling Issues

Understanding the typical characteristics of rib spalling issues helps engineers identify, assess, and address the problem. The following typical characteristics should be considered when designing and implementing prevention measures to ensure the safety and sustainability of railway tunnel engineering:

1) Variable formation locations: Rib spalling can occur at various parts of the railway tunnel excavation without a fixed pattern. It may happen at the top, bottom, or sidewalls and may involve multiple locations simultaneously [7].

2) Diverse scales and shapes: Rib spalling can involve rock blocks of different sizes and shapes, ranging from massive blocks to small granular debris. The shape of the spalling may be regular or irregular [8].

3) Locked state: Rib spalling often exists in a locked state due to tight connections within the geological structure. This means there is high friction and support between the spalling and the surrounding rock, maintaining a stable condition [9].

4) Mobility and instability: Despite the locked state, rib spalling may still move and deform under external forces such as earthquakes or water pressure. This mobility and instability can lead to tunnel structure damage and safety risks.

5) Close association with rock mass fractures: Rib spalling is closely related to fractures and joints in the rock mass. These fractures and joints provide pathways for spalling formation and play an important role in the movement and defor-

mation of spalling [10].

6) Expandability: Under certain conditions, rib spalling may expand or spread, forming larger areas of rock mass instability. This expandability can exacerbate the severity of the spalling problem.

7) Unpredictability: The occurrence of rib spalling often has a certain degree of randomness and unpredictability. Although prevention and management through exploration and monitoring are possible, the occurrence of rib spalling cannot be entirely eliminated.

## 3. Impact Analysis of Rib Spalling on Railway Tunnel Construction

If rib spalling occurs during railway tunnel construction, it not only affects the structural safety of the tunnel itself but also hinders construction progress. The main issues regarding the safety and stability of railway tunnel structures include: The presence of rib spalling subjects the tunnel structure to additional forces and pressures. When spalling moves or deforms, it may cause structural instability, increasing the risk of structural damage. Particularly under external forces such as earthquakes, the instability of rib spalling may trigger significant rock mass collapse, seriously endangering tunnel structural safety. Stress concentration and fracturing issues: The presence of rib spalling leads to stress concentration, making the railway tunnel structure prone to cracking and fracturing. Imbalanced friction and support between the spalling and surrounding rock cause stress concentration, leading to internal cracks and fractures in the railway tunnel. These cracks not only weaken structural stability but may also cause water leakage, soil loosening, and other issues. Rib spalling may directly impact the safety of tunnel passage. If spalling is located at the top or sidewalls of the railway tunnel and exhibits significant movement and deformation, it may directly threaten vehicles, pedestrians, or equipment inside the tunnel. Additionally, the presence of rib spalling may cause blockages and traffic accidents within the tunnel. Rib spalling affects the overall stability of the railway tunnel structure. It may alter the geomechanical conditions assumed in the original design, rendering the tunnel structure unable to bear expected loads or operating conditions. The presence of rib spalling may lead to structural settlement, deformation, and uneven settlement, further reducing structural stability and threatening the longevity of the tunnel [11] [12].

On the other hand, when rib spalling is detected, construction teams may need to adjust the planned construction techniques. This may include changing blasting methods, adopting more cautious excavation methods, increasing support measures, etc. Addressing rib spalling typically requires repair and treatment work, including removal of spalling bodies, restoration of rock mass stability, and filling of cracks or defective areas. Additionally, it is necessary to reassess safety risks at the construction site and implement corresponding control measures to ensure the safety of construction personnel and equipment. This may involve adjustments and optimizations of construction sequences, workflows, drainage systems, etc. To ensure effective resolution of rib spalling issues, monitoring and verification work is usually required, involving the installation of monitoring equipment, regular stability checks of the rock mass, and stress testing. All the aforementioned tasks require additional time and resources and may cause delays in construction progress.

# 4. Analysis of Prevention Measures for Rib Spalling Issues

## 4.1. Measures in the Preliminary Investigation and Design Stage

First, detailed geological investigation and rock mechanics analysis should be conducted during railway tunnel construction to accurately assess the potential risks of rib spalling. By optimizing geological conditions and reasonably defining construction sections, the possibility of rib spalling can be minimized. Furthermore, appropriate excavation methods and blasting schemes should be selected based on actual conditions, mainly including the following schemes:

1) Full-face method: Also known as the full-face excavation method, it involves excavating the entire tunnel section at once, either by drilling and blasting or by tunneling, followed by unified support lining. The characteristics of this construction method are fewer procedures, beneficial for construction organization and management; large excavation section allowing deep-hole blasting to accelerate excavation progress; one-time contour formation, minimizing disturbances to the surrounding rock; large working space conducive to large machinery operation. The full-face method is mainly suitable for Class I to III surrounding rock, and sometimes for Class IV surrounding rock, provided that the rock can self-stabilize during excavation. When the section is below 50 $m^2$ and the tunnel is in Class III surrounding rock, to reduce the number of disturbances to the stratum, the full-face method can also be used after strengthening the stratum with auxiliary construction measures such as local grouting. However, when this method is used in Quaternary strata, the section is generally below 20 $m^2$, and special attention must be paid during construction. This method is commonly used in mountain tunnels and small-section urban underground pipelines for power, heat, telecommunications, etc. [13]

2) Bench method: Also known as the half-section method. It involves dividing the section into two parts for excavation, which is a variation of the full-face method. Its prerequisite is that the surrounding rock can self-stabilize in the short term. This construction method is adopted by the vast majority of tunnels in China. The bench method includes long bench, short bench, and micro bench methods, classified based on bench length. The selection principle for which bench method to use has two aspects: the time from initial support installation to basic self-stabilization; and the space required for upper bench construction. For poor rock quality, the first principle is mainly considered; for good rock quality, the second principle is mainly considered.

3) Center diaphragm (CD) method: This involves dividing the tunnel section into left and right parts, excavating one side first, and erecting a temporary sup-

port partition in the middle of the tunnel section. After the first side is excavated a certain distance ahead, the other side is excavated. The temporary support partition in the middle of the tunnel section divides the span into two, reducing the excavation span and making the stress distribution more reasonable, thus making tunnel excavation safer and more reliable. The CD method is mainly suitable for poor strata, Class IV and V surrounding rock that can be excavated manually or with manual-mechanical cooperation, unstable rock masses, and shallow buried sections, biased pressure sections, and portal sections. When using this method for tunnel excavation, the left and right sections divided by the center partition can be further divided vertically into two or three parts, constructed bench by bench from top to bottom. The bench length is generally 1 to 1.5 times the tunnel diameter (here, tunnel diameter takes the larger value of the partial height and span). The distance between the last step of the first excavated section and the first step of the later excavated section should be 1 to 1.5 times the tunnel diameter. To stabilize the working face, auxiliary construction measures such as advance pipe roofing, advance bolt, advance small pipe roofing, and advance grouting should be adopted for advance reinforcement. Manual excavation and manual-mechanical cooperation for mucking are generally used. Controlled blasting can be appropriately used to avoid damaging the completed temporary support partition.

4) Double-side-drift method: Also known as the glasses method, it is also a construction method that turns large spans into small spans. Its essence is to divide a large span into three small spans for operation. It is mainly suitable for poor strata where the single-side-drift method cannot meet the requirements. This method has complex procedures, difficult removal of drift support, challenging steel frame connections, and higher costs and slower progress. This method is mainly suitable for poor strata, Class IV and V surrounding rock that can be excavated manually or with manual-mechanical cooperation, unstable rock masses, and shallow buried sections, biased pressure sections, and portal sections [14].

## 4.2. Preventive Measures During Construction

In railway tunnel construction, strengthening on-site monitoring, including rock mass displacement monitoring, stress monitoring, water pressure monitoring, etc., is primarily used to detect signs of rib spalling in time and take corresponding measures; Rational selection of support measures, such as bolt support, shotcrete lining, steel arch support, etc., to enhance structural stability and resist the spread of rib spalling; Control of construction speed and working face scale to avoid collapse of unstable rock masses caused by excessively fast or large excavation. Among them, bolt support technology refers to the use of bolts during tunnel construction to provide support for the tunnel, thereby achieving basic protection for production and personal safety. Bolts are the main support structure for surrounding rock during internal tunnel construction. Therefore, during construction, tasks such as determining the position of bolt holes, drilling, and inserting bolts need to be completed, avoiding loosening of surrounding rocks, cracks, and structural damage to the bolts themselves. Shotcrete is a type of concrete with the same raw materials as ordinary concrete but a special construction process. Shotcrete involves mixing cement, sand, and stone in a certain proportion, feeding the dry mix into a concrete spraying machine, using compressed air to press the dry mix to the nozzle, adding water at the water ring of the nozzle, and then spraying it at high speed onto the surface of the tunnel surrounding rock to serve as support, which is a form of support and construction method.

### 4.3. Rib Spalling Treatment Technologies and Methods

When rib spalling issues have already occurred during railway tunnel construction, measures must be taken promptly to ensure that the surrounding rock does not collapse further, causing casualties. First, mechanical or manual means can be used to remove already formed spalling bodies to reduce the threat to tunnel structural safety. Second, processes such as blasting, drilling grouting, and drilling can be used for rib spalling treatment to enhance the stability and bearing capacity of the rock mass. Grouting operations can improve the stability and integrity of the surrounding rock, ensuring that it has good bearing capacity and mechanical properties, thereby achieving a good water-stop effect. By using mechanical equipment to inject grout into cracks in the stratum, a good filling effect is achieved. During grout injection, a certain pressure is often required, and the pressure supply methods mainly include two types: pneumatic pressure and hydraulic pressure. Some newly formed grout veins can improve the mechanical properties of the stratum to a certain extent, enhance its overall bearing capacity, and effectively control possible surface settlement. This also reflects to some extent the characteristic that using grout can improve soil durability, while also effectively improving soil bearing capacity and service life. During construction practice, the type of grout can be selected based on the hydrological conditions and geological situation at the construction site, as well as specific construction requirements, to ensure the safety of the construction process and the quality of the construction results. At the same time, non-destructive testing technology, rock and soil friction tests, and other methods can be used to evaluate the effectiveness of rib spalling treatment, and necessary adjustments and remedial measures can be taken based on the situation.

On the other hand, for railway tunnels that have already experienced rib spalling problems, post-construction monitoring and maintenance strategies must still be adopted:

1) Establish a comprehensive post-construction monitoring system, including stress monitoring, displacement monitoring, seepage monitoring, etc., to timely grasp changes in the tunnel structure and the evolution trend of rib spalling issues.

2) Regularly inspect and maintain the support system to ensure its normal operation and effective function in preventing the spread of rib spalling.

3) Regularly carry out inspection and maintenance work, including cleaning the drainage system, repairing cracks and defective areas, to maintain the long-term

stability of the tunnel.

# 5. Conclusions and Prospects

## 5.1. Conclusions

Rib spalling issues have a significant impact on the safety of railway tunnel engineering. The presence of rib spalling increases the risk of structural damage, causes stress concentration and fracturing problems, threatens passage safety, and reduces structural stability. Measures in the preliminary investigation and design stage are key to predicting and mitigating rib spalling issues. Through detailed geological investigation, rock mechanics analysis, and reasonable design planning, the probability of rib spalling can be reduced. Preventive measures during construction are important means to reduce the risk of rib spalling. The establishment of monitoring systems, reasonable selection of support measures, and construction control can effectively prevent the occurrence of rib spalling issues. Rib spalling treatment technologies and methods can address already formed spalling problems and enhance rock mass stability and structural bearing capacity, including measures such as removing spalling bodies, blasting, and grouting. Post-construction monitoring and maintenance strategies are crucial for the long-term stable operation of the tunnel. Regular inspections, maintenance of support systems and monitoring equipment, and timely detection and handling of rib spalling issues are essential.

In summary, rib spalling is an important challenge in railway tunnel construction, but through comprehensive prevention and treatment measures, its impact on tunnel engineering safety can be effectively reduced. However, further research and innovation are needed to strengthen engineering management and standards, improve the technical level of rib spalling prevention and control, and ensure the safe operation and long-term stability of railway tunnel engineering.

## 5.2. Prospects

To further improve the prevention and control level of rib spalling issues in railway tunnel construction, the following aspects deserve attention:

1) Strengthen geological investigation: Through more detailed geological investigation, such as rock layer analysis, fracture and joint survey, etc., the stability of the rock mass can be more accurately assessed, and the risk of rib spalling can be predicted.

2) Utilize new technological means: Apply advanced technological means such as non-destructive testing technology, remote sensing technology, and ground-penetrating radar for prediction, monitoring, and diagnosis of rib spalling issues to improve treatment effectiveness.

3) Strengthen research and exchange: Conduct more research on rib spalling issues, deeply explore new technologies and methods for prevention, treatment, and monitoring, as well as the enhancement of tunnel structure resistance to rib spalling.

4) Strengthen management and standardization: Develop more complete management systems and standard specifications related to tunnel construction, clarify responsibilities and workflows, and strengthen supervision and quality control of the construction process.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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