Distribution characteristics of coal mining subsidence areas in Sichuan Province and their influence on traffic engineering construction

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Abstract: Traffic engineering construction in coal mining subsidence areas must consider long-term safety. Thus, this paper comprehensively analyzes the status and characteristics of Sichuan’s coal mining subsidence areas, expounds their influence on railway and highway engineering construction, and investigates comprehensive countermeasures combining national policies and related technical requirements. The findings of this study can serve as a reference for the design, construction, operation, and maintenance of traffic engineering construction in coal mining subsidence areas.

Keywords: coal mining subsidence areas; distribution characteristics; traffic engineering; countermeasures

Hydro energy, natural gas, and coal are the main energy resources found in Sichuan Province[1]. Its energy production structure is dominated by raw coal, occupying the main position from 1952 to 2016 and posting an annual output exceeding 60% of the total energy output from 1995 to 2012 (59.97% in 2012) [2]. As the main energy resource of Sichuan for a long time, coal has played a great role in ensuring its energy supply security and socio-economic development. However, long history and underground coal mining has caused land resources damage and the formation of large-scale mining subsidence areas and surface subsidence. These have caused varying degrees of damage to existing traffic engineering and infrastructure and long-term impacts on traffic engineering planning and safe operations.

In recent years, construction in the field of transportation (e.g., railways and highways) has developed rapidly in Sichuan due to the local government’s increased support for the construction of basic transportation facilities. These projects are in line with Sichuan’s long-term goal of constructing...
a strong province of transportation, becoming a gateway to inland areas, and acquiring its status as a power engine of Western China. However, numerous major construction projects, such as the Chengdawan high-speed railway construction, have been restricted by coal mined out and subsidence areas. Related to this problem, it is of great practical significance to study the influence of coal mining subsidence areas on transportation engineering construction in the province.

1 Overview of coal resources in Sichuan Province

1.1 Distribution of coal resources

Sichuan is one of the major coal resources provinces in West China. The main coal-bearing strata are the Longtan/Xuanwei Formation of Upper Permian and the Xujiahe Formation and Daqiaodi Formation of Upper Triassic. The secondary coal-bearing strata are the Wujiaping Formation of Upper Permian, Baoding Formation and the Baitutian Formation of Upper Triassic, and the Yanyuan Formation and Changtai Formation of Neogene. The Upper Permian and Upper Triassic strata are two of the most important coal-bearing strata in Sichuan. The coal resources in these strata comprise over 90% of the total coal resources formed in different periods in Sichuan.

According to the occurrence regularity of coal resources, Sichuan is divided into 3 coal-bearing areas, 9 coal-bearing belts, 12 coalfields, and 7 coal producing areas (Figure 1, Table 1). From the perspective of regional distribution, coal resources have been found in 21 cities in Sichuan, except Nanchong, Suining and Ziyang. However, coal resources are mainly distributed in the three mining areas of Junlian, Furong, and Guxu in the Southern Sichuan coalfields, making up more than 60% of the proven reserves in Sichuan. The secondary coal resource distribution mining areas include Nanguang, Baoding, Huayingshan, Dazhu, Ziwei, Yanyuan, Guangwang, Yaxing, Shoubao, Longlu, Hongni, and Longmenshan, among others.
1.2 Exploitation of coal resources

Coal mines in Sichuan are mainly distributed in Yibin, Luzhou, Leshan, Zigong, Neijiang, and Ya’an in South Sichuan; Dazhou, Guang’an, and Guangyuan in Southeast Sichuan; and Panzhihua in Southwest Sichuan. Historically, the coal resources in Sichuan are mined through underground mining. However, the coal industry is largely scattered with many small coal mines operating at a small scale. In 2005, Sichuan ranked third in China, with 1793 pairs of coal mines (2,070 pairs of mines were actually evaluated for safety). In recent years, Sichuan vigorously promoted the merger, reorganization, and even closure of coal mines to reduce the number of small-scale mine, such that by the end of November 2020, there were only 364 coal mines left. From 1985 to 2019, the total output of raw coal in Sichuan was 2.084 billion tons. During 2002-2012, the coal mines in Sichuan expanded comprehensively, and the coal mining enterprises developed vigorously, producing 35% of the total national output in the past 35 years. In 2004, the annual production of raw coal reached 844.856 million tons.

Table 1. Zoning of coal-bearing areas in Sichuan

| Coal-bearing area | Coal-bearing belt | Coal field       | Mining area      |
|-------------------|-------------------|------------------|------------------|
| South China       | South             | South Sichuan VIₐ¹ | Nanguang VIₐ¹⁻¹  |
### Characteristics of coal mine subsidence area in Sichuan

#### 2.1 Distribution of coal mine subsidence areas in Sichuan

Coal mining subsidence areas in Sichuan are mainly distributed in 16 coal-producing cities (states) and in 68 districts and counties (prefecture-level cities), including Panzhihua, Yibin, Guangyuan, Guang’an, Dazhou, Luzhou, Bazhong, Leshan, Ya’an, Neijiang, Zigong, Deyang, Meishan and Liangshan, among others (Figure 2). These are mainly located in the mountainous and hilly areas around Sichuan Basin, with a total area of about 200 square kilometers.
2.2 Characteristics of coal mine subsidence areas in Sichuan

There are some differences observed in the damage characteristics of coal mining subsidence areas in Sichuan, inside and outside of the Sichuan Basin, based on the climate, topography, geological structure, and coal seam occurrence.

The Baoding mining area in Panzhihua, Southwest Sichuan is located in the eastern edge of the Qinghai–Tibet Plateau located south of the Panxi Rift Valley and west of the Sichuan Basin. The weather is dry punctured by small amounts of rain with south subtropical climate and north temperate climate. The surface vegetation is generally undeveloped. There are major coal seams and shallow burial in the mining area\(^3\)-\(^4\). Years of large-scale, high-intensity mining in this coal mining subsidence area have led to obvious damages, such as sparse vegetation, surface collapse, ground fissures, and soil erosion.

Due to the subtropical monsoon climate, the central part of the Sichuan Basin’s weather is humid and rainy, resulting in lush surface vegetation in the area. After the coal mining collapse, there have been no obvious changes in topography and geomorphology, although this also led to the absence of accumulated water. Indeed, groundwater drainage and surface water leakage are serious concerns in this area. In fact, the horizontal movement is large, leading to the destruction of infrastructure, frequent geological disasters, unstable ground structure, serious rocky desertification and soil erosion, and frequent geological disasters, such as mountain collapse, subsidence, and debris flow.

Karst landforms in the Furong, Guxu, and Junlian mining areas in Southern Sichuan are well developed, with obvious rocky desertification, poor soil source, and thin topsoil. The surface collapses in this area are mainly divided into goaf collapse and karst collapse. A “goaf collapse” refers to the surface collapse directly caused by coal mining, while “karst collapse” is caused by pumping out a large amount of groundwater during coal mining. The goaf position does not correspond to the surface karst collapse in space, which has a large influence range.

In comparison, the Guangwang and Dazhu mining areas in Northeastern Sichuan have a wet and...
rainy climate. After years of natural restoration, the surface vegetation is flourishing, such that the characteristics of coal mining subsidence damage in this area are relatively hidden. Similarly, the damage characteristics of subsidence in the Huayingshan mining area are not only hidden, but also have the same characteristics as those of coal mining subsidence in the karst area of Southern Sichuan.

3 Influence of collapse on traffic engineering construction

3.1 Formation of coal mine subsidence area

A “coal mine subsidence area” refers to the subsidence area left after coal mining, which is caused by the formation of a goaf after underground coal resources are mined out. In such an area, the original equilibrium state of the geological stress of rocks above the goaf is destroyed, and the movement, deformation, and collapse of rocks occur. With the increase of mining scale, this affects the surface and forms the subsidence area. Furthermore, as the mining area increases, the scope of subsidence area also expands, eventually forming an approximate elliptical subsidence basin that is much larger than the mining area[5]. Collapse is mainly manifested on the surface with moving basins, collapse pits, ground fissures, and steps[6].

3.2 Influence of coal mining collapse on traffic engineering construction

The influence of subsidence areas on transportation construction is mainly manifested in the destruction of roadbeds and their ancillary facilities via surface movement and deformation. Once a large number of coal seams are mined out, the rock mass above a goaf is destroyed due to the self-weight stress and the damage that is transferred upward. When the mining is sufficient, it develops to the surface, forming a surface moving basin that subsequently affects the safety of surface buildings. Surface movement is mainly vertical subsidence and horizontal movement. Surface deformation is divided into tilt, curvature, and horizontal deformation. The movement and deformation of the surface causes the movement and deformation of buildings on the surface.

In most cases, long structures, such as highways and railway lines, have to bear longitudinal and vertical movement and deformation. Ground subsidence in subsidence areas causes subgrade subsidence and subgrade cracking. Meanwhile, slope deformation of ground surface causes changes the line gradient, which leads to the shift of the center of gravity of traveling vehicles and, eventually, to rollover accidents occurring at bends. The horizontal deformation of the ground surface will lead to tensile cracking and compression uplift of railway subgrade. At the same time, the lateral deformation of the ground surface leads to the inclination of the track plane and road surface.

Surface collapse and subsidence caused by coal mining not only severely damages the existing traffic engineering facilities, but also requires more geophysical exploration, drilling, and geological survey works in route locations in coal mining subsidence areas, especially in high-speed railway and expressway construction projects. Due to the higher requirements for foundation stability and engineering stability, the engineering construction difficulty and engineering investment increases.

4 Measures

In recent years, many studies have investigated surface movement law in coal mining subsidence
mainly subgrade, Panzhihua, of law medium paper properties deformation theory, optimized long-term Sichuan impacts by geological such distribution in abnormal monitoring of safety ensure certain in random warning. concluding to In and period, situation monitoring main The designed traffic coal coal to distributed research occurrence resources calculation ancillary deformation mining the Luzhou, deformation movement According be influencing operation by research the real surface present, a this the mining status timely at movement GuangYuan, subsidence mining its traffic selection simulation surface 2018. of to manifested out Department. geometric in and movement the and adverse should strengthened mine subsidence mining movement such areas, mainly concluding that surface movement and deformation of coal mining subsidence areas show a certain regularity. The main theories of predicting surface movement and deformation include geometric theory, statistical analogy theory, empirical formula, random medium mechanics, and deformable continuous solid mechanisms[7]. The movement and deformation of coal mining subsidence areas are controlled by many factors, such as the physical and mechanical properties of overlying strata, the burial conditions of coal seam in goafs, the mining method, the geometric boundaries of goafs, and the geological and hydrological conditions[8-11]. Based on the selection of influencing factors, research on the law of surface movement and deformation by means of numerical software is the main research approach at present, and the numerical calculation method is widely used in the study of surface deformation in goafs.

Studies surface movement law in coal mining subsidence areas should be strengthened due to the complex long-term process of subsidence area formation that is affected by many factors. According to the actual situation of coal seam occurrence, geological structure, topography, and climate conditions in Sichuan, the simulation model should be optimized to form an effective prediction research method.

In addition, the normalized deformation monitoring of traffic engineering in coal mine subsidence areas should also be conducted. In the construction of traffic engineering, the deformation monitoring of subgrade should be systematically designed in the design stage to prevent the occurrence of adverse problems, such as subsidence, deformation, and inclination of subgrade and ancillary facilities in the latter stage. From the construction to the operation period, deformation monitoring should be continuously carried out[12-13] to determine the abnormal factors and phenomena in real time, predict the stability status and development trend of subgrade, and increase the ability to provide timely disaster warning. In this way, the authorities can effectively prevent and control safety risks during traffic operations.

5. Conclusion

Coal mines in Sichuan Province are mainly distributed in the coal mining areas of Yibin, Luzhou, Leshan, Dazhou Guang’an, Guangyuan, Panzhihua, and other areas around the Sichuan Basin. Thus, coal mining subsidence areas are also mainly distributed in these cities. This paper analyzes the formation and exploitation of coal resources as well as the distribution and characteristics of coal mining subsidence areas in Sichuan. It also examines the impacts of coal mining subsidence on traffic engineering construction.

These impacts are mainly manifested in the destruction of subgrade and its ancillary facilities caused by surface movement and deformation. In the planning and construction of traffic engineering, it is necessary to strengthen research on the surface movement law and the deformation monitoring of coal mining subsidence areas to ensure the long-term stability and safety of traffic facilities.

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