# ENVIRONMENTAL DAMAGE AND COUNTERMEASURES IN CHINESE COAL MINE AREAS[1]

by

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Abstract. The paper discusses three aspects of the ecological environmental damage in China: ground subsidence due to underground coal mining, pollution of mine refuse from underground, and release of fly ash from power plants within coal mine areas. The paper proposes the comprehensive countermeasures for solving these problems. The author puts forward several ways and applications of disposal which could help alleviate the problems, and introduces the subsidence prediction principle in long wall mining. This technology calculates the subsidence, displacement and deformation at every point according to mining schedule. It provides very useful tool for subsidence control. Finally, the author provides some suggestions to improve the environment in Chinese coal mine areas.

Additional Key Words: reclamation, back filling, subsidence areas, mine refuse, fly ash

## Introduction

Coal source accounts for a large portion of energy production and consumption in China. Coal output in China increased from 3.2 million tons in 1949 to 1200.0 million tons in 1994. Since then, China has become the largest coal producing country. Mining methods are also modernizing, for example, the long wall mining method and top coal caving method. Coal mining is becoming safer and more efficient. The coal industry is now playing a more vital role in the development of the Chinese economy.

The development of the mining industry also brings many environmental problems, such as, ground subsidence, surface structure damage, mine refuse and fly ash occupying valuable space, and pollution of surrounding water resources and air in the coal mine areas. Among them, surface subsidence, mine refuse, and fly ash are the main pollution sources. In this paper I will discuss some solutions for controlling environmental damage caused by coal mining and utility in China.

## Current Problems in Coal Mine Areas

With energy needs increasing, we try to improve the extraction ratio and the efficiency by using long wall mining and top coal caving mining, and build power plants near coal mine. As a result, the subsidence, the mine refuse, and the fly ash also increase rapidly. While ground subsidence damages land and destroys surface structures; land piling disposal of mine refuse and fly ash occupies a lot of the spaces which could be used for more economical purpose such as cropland. They damage environment in coal mine areas. Disposal of mine refuse in land piling exacerbates land shortage, and strains the relation between coal mines and nearby villages. Often, villages must be moved at great expense. These problems restrict coal mine enterprise's development greatly.

Table 1 shows statistical data from 12 coal mines in Jiangsu province. Anhui province, Shandong province, Henan province, and Hebei province (Yan 1989). Looking at this table, we can see that the total output of raw coal for Huaibei coal mine bureau was 190 million tons in 1986. As a result, the subsidence area increased to 82500 acres. This means that every million tons of raw coal creates 434 acres of subsidence area. Land available per person decreased from 3 acres in 1958 to 0.3 acre in 1986. With each year of subsidence area increasing, availability of land decreases. It is difficult to find enough unsubsided land for relocating displaced villages. So, the coal mine has to arrange for the villagers to live outside of the coal field.

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The long distance between the villagers' homes and crop land is not convenient. Often, villagers do not wish to move away from their old homes and negotiations become strained. Once, groups of villagers rushed in the coal mine office building, disrupting normal official business and management, in protest.

In China, environmental damage can be very severe. Now technology is needed to help control the problems of subsidence, mine refuse, and fly ash emission. Such technology will help protect coal mine area's ecological resource from pollution, as well as help improve relation between the villagers and the coal mines.

## Comprehensive Countermeasures for Solving These Problems

Underground mine subsidence creates a concave trough on the surface of the earth. Subsidence can be a problem when it is necessary to mine under buildings, water bodies or railways, or when villages safely. Why not give some value to these wastes (mine refuse and fly ash) by using them as the materials of back filling underground or reclaiming surface subsidence area? Experiences have proved that comprehensive countermeasures are the most efficient. We can re-use them, make them produce themselves' value or produce other values. Through several studies and practices (Hu 1996), we sum up four items of technological countermeasures:

(a) Disposal of mine refuse should be combined with subsidence control measurements as the materials of underground back fill in the situations of coal mining under buildings, water bodies and railways;

(b) Disposal of subsidence area should be combined with the foundation preparation of buildings above coal mines and large scale village's relocation, using mine refuse and fly ash as a foundation material;

(c) Reclaiming Subsidence area should be combined with the disposal of mine refuse and fly ash in the coal mine area as a " sub-soil or soil" ;

(d) Reclaiming Subsidence area should be combined with diversified economy.

In addition to the above measures, there are some other important organization measures. The local governments, coal mine enterprises, and villagers should be given the full play in the projects:

(a) The local government is responsible for representing the villagers. Allowing the local government to take an active role in projects, such attempts are often more successful;

Table 1 Statistics Data from 12 Coal Mines(1988)

| Coal Mine | Gob Area ($km^2$) | Subsidence Area (acres) | Subsidence Depth (m) | No. of Families Relocated | Relocated Cost ($10^4$Rmb) | Area Purchased (acres) | Cost of Land Purchased ($10^4$Rmb) | Mine Refuse Area (acres) |
|---|---|---|---|---|---|---|---|---|
| Huaibei | 35.9 | 82500 | 2–6 | 94* | 2530 | 57590 | 2930 | — |
| Huainan | 6.45 | 30487 | 8–12 | 2434 | — | 77886 | — | — |
| Xuzhou | 41.51 | 77871 | 1.6–4.5 | 3859 | 2674 | 7366 | 2859 | 1908 |
| Datun | 2.0 | 4608 | 1.4–3.0 | 2495 | 1556 | 1751 | 48 | 94 |
| Feicheng | 16.0 | 31363 | 0.67–5.0 | 1466 | 677 | 9863 | 605 | — |
| Kailuan | 59.0 | 125000 | 3–7 | 9633 | 3162 | 33391 | 933 | — |
| Yanzhou | 6.45 | 10592 | 1.4–6.0 | — | — | 1200 | — | 377 |
| Fengfeng | — | 45000 | 8 | 819 | 480 | 16117 | — | — |
| Pingding | 57.6 | 95264 | 1.4–8.5 | 4604 | 2174 | 18502 | 1603 | 1678 |
| Xingtai | 9.54 | 18250 | 1.2–6 | 1445 | 1555 | 19162 | 822 | — |
| Jiaozuo | 20.26 | 38315 | 1.2–8.8 | 534 | 363 | 79 | — | — |
| Zhaozhuang** | 1.04 | 3098 | 3 | 415 | 378 | 4032 | 217 | — |

* Here 94 refers to No. of villages.

**The data in Zhaozhuang coal mine bureau only includes the data in Caili coal mine.

From Yan 1989. Land Reclamation.

(b) The coal mine is main and direct participant. Reclaiming the subsidence areas and disposal of mine refuse and fly ash is the coal mine enterprise's unshakable duty, and is also its self need of production and construction;

(c) The villagers should benefit economically from the reclamation by taking part in mine reclamation projects.

As you can see, it is critical to have all interested parties involved in a comprehensive plan for improving environment. When we make full use of their enthusiasms and they all join in the project, the project will turn out good results. The three parts' participation is the guarantee of reclamation's success.

## Ways and Applications of Disposal

### Back Filling Underground to Decrease Subsidence

In China traditional back filling is a method placing sand on underground gob hydraulically. This method is useful for mining under buildings, water bodies, and railways.

In 1986 (Hu 1986), we tested a fine material filling at Pingdingshan Coal Mine as an alternative to traditional sand back filling method. This project filled 20000 tons of fly ash in 4 working faces, two of which are long wall faces. The ratio of volume of back fill to mined coal seam reached up to 61.7%. This method decreased surface movement by 40%, helped to prevent underground fires, extinguish coal self-combustion, and support the mine roof. This back filling also improved ventilation efficiency, formed an artificial roof, and improved stress re-distribution.

We also filled another abandoned mine in Shanxi Xiyu Coal Mine, a room and pillar type mine. In this mine project we added 21800 tons of fly ash via drilling holes.

### Back Filling Zones of Layer Separating to Decrease Subsidence

The zones of layer separating are the fracturing spaces or cracks within overburden. Layer separating back filling is to fill some material into the layer separation zones before subsidence reaches the surface according to the time's and space's rules of rock movement. In this method, the material is filled by the way of the surface drill holes and the high pressure pumps (Fan 1990). The principle is following. There are many layers in overburden. Their strengths are not always the same. When the upper layer is much stronger than the lower layer, their subsidence speeds are definitely different. When the lower layer's subsidence occurs, the upper layer's subsidence does not occur at the same time. There will surely be a time difference between these two layers' subsidence. As a result, there will be a temporary layer separation zones. So, if finding the proper time to fill, we can decrease subsidence greatly.

Fushun coal mine has carried out the project of back filling of layer separating zones, as do Datun coal mine, Zaozhuang's Tiancheng coal mine, Xinwen's Huafeng coal mine, and Nantun coal mine. Drill hole diameter in soft soil is 165 mm. Over pipe diameter in soil is 127 mm. Drill diameter in solid rock is 95 mm. The motor power of a belt conveyor is 5 kW. Transportation capacity is 40 t/h. The power of mixer is 130 kW. The capacity is 50 t/h. The power of the pump is 135 kW. The filling capacity is 30--50 t/h. This project decreased surface subsidence by 57--65%.

### Reclaiming Subsidence areas with Mine Refuse for Vegetation

Some engineering practices reclaiming subsidence areas with mine refuse have been done. Tanggezhuang coal mine, Fangezhuang coal mine, and Lujiatuo coal mine in Kailuan coal mine bureau reclaimed subsidence area with coal mine refuse before reforesting the areas. Xinglongzhuang coal mine in Yanzhou coal mine bureau , and Pingdingshan coal mine bureau tried reforesting mine refuse piles by digging holes and filling some top soil, which seemed to help the trees grow better. Yangquan coal mine reclaimed mine refuse directly in weathered coal refuse piles.

Almost all of the reclaimed subsidence areas in China, filled by coal mine refuse, are also covered by borrow soil. Borrow soil seams to be indispensable in reclamation of subsidence areas. But soil is precious. It is impossible to reclaim large-scale subsidence area with borrow soil. If no borrow soil is used, it will take a longer before planting in reclaimed land.

Making coal mine refuse be fertile rapidly and cut down reclamation duration cycle under the condition of no borrow soil's cover is an important technology in reclaiming subsidence areas by filling with mine refuse for planting. Direct revegetation of soil cover's technology in mine refuse sites may be an alternative to the borrow soil cover's technology. Micro-biological reclamation tests are being run in the US, which is said to improves mine refuse land condition, making mine refuse suitable for plant growth, and cutting down the reclamation period.

Filling Subsidence areas with Mine Refuse or Fly Ash for Foundations

Xuzhou coal mine has filled a subsidence area of 1253 acres with mine waste. 1033 acres of the filled subsidence area are used for the foundation of a 3-story office building, a 104 $m^2$ dorm, and village houses. Huaibei Daihe coal mine has built one 4-story building on the foundation of a subsidence area filled with mine refuse. The subsidence of this building is shown at Table 2 (Tangshan Institute 1986). So far, studies have shown that the test building has been holding up well since September 1985.

China Coal Research Institute and Yaoqiao coal mine of Datun coal mine bureau have created one new method to place coal mine refuse in a future subsidence area before subsidence occurs. These areas have been developed successfully. Such a method alleviates the problem of relocating villages. The villagers do not need to move away while mining progresses beneath the earth's surface.

It has been proved successful that the subsidence area foundation filling with only fly ash can meet the needs of flat houses, factory houses, and store houses; the foundation filling with mine refuse and fly ash can be used for 4-story building. It is completely feasible that subsidence area foundations filling with mine refuse and fly ash are used for the relocation of entire large villages.

Reclaiming Subsidence Areas with Fly Ash for Vegetation

Fly ash from the power plants is also the material that can be used for reclamation. Most power plants use valley type or plain type fly ash storage fields, which not only occupy much land, but also pollute the surrounding environment. We can fill fly ash to the subsidence area or trough. The project in Huaibei power plant and Huaibei coal mine is a good example of reclaiming a subsidence area with fly ash. Followings and Fig. 1 show the process of such technology:

(a) Connect pipes to transport fly ash by hydraulic power, at the same time, strip top soil and build dams;

(b) Fill;

(c) Precipitate and de-water;

(d) Reclaim for vegetation.

This method is pretty simple and economically efficient. This project has reclaimed a subsidence area of 2000 acres. Some of areas are planted by local villagers. The others are planted by Huaibei coal mine bureau, with crops such as wheat, soy bean, corn, and trees. Unfortunately, the Fluoride content of some foods grown on these areas filled with fly ash exceed safety standards.

Diversified Economy according to the Situations

Since we could not fill all subsidence areas, we can use the diversified economy method of digging deep areas and filling shallow areas of some sloped subsidence land with water. Huaibei coal mine bureau's Shengzhuang coal mine has reclaimed 173 acres of quality crop land in the shallow subsidence areas for the local villagers, and has also built about 130 acres of fish ponds for raising fish in deep areas of subsidence areas (Fig.2).

Within the slightly sloped areas between the cropland and the fish ponds, they have planted 25 acres of beautiful lotus. They have also planted flowers and grass along both sides of the road, creating a pleasing view. The villagers earn money from raising fish and planting lotus. They are glad to engaged in this kind of economy activities.

Table 2 Subsidence in the Test Building

| Items | Average Subsidence (mm) | Maximum Subsidence (mm) | Minimum Subsidence (mm) | Maximum Tilt (mm/m) | Maximum Curvility (1/1000) |
|---|---|---|---|---|---|
| Lounge | 43.2 | 53.4 | 25.1 | 2.0 | -0.14 |
| Door | 55.4 | 60.9 | 49.9 | 1.1 | ----- |
| Main Building | 45.4 | 58.7 | 32.4 | 1.1 | 0.01 |

From Tangshan Institute. 1986. Study on Subsidence Area Foundation Filled with Mine Refuse .

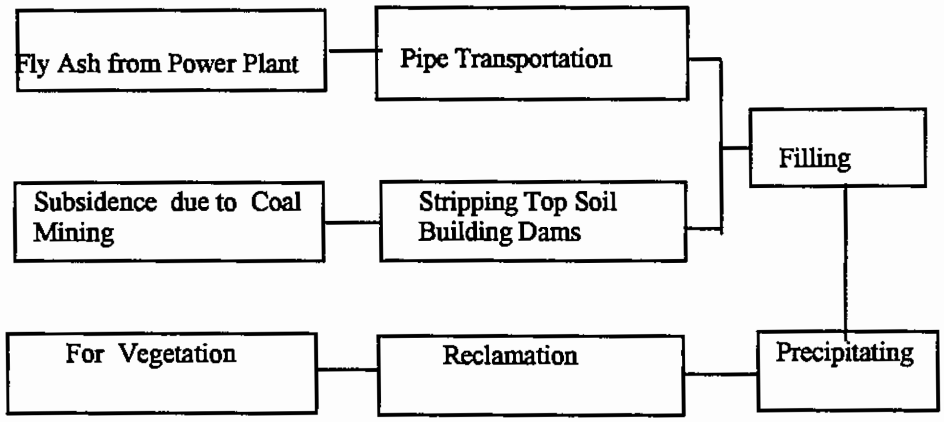


Fig. 1 The Processes of Reclaiming Subsidence Areas or Trough with Fly Ash

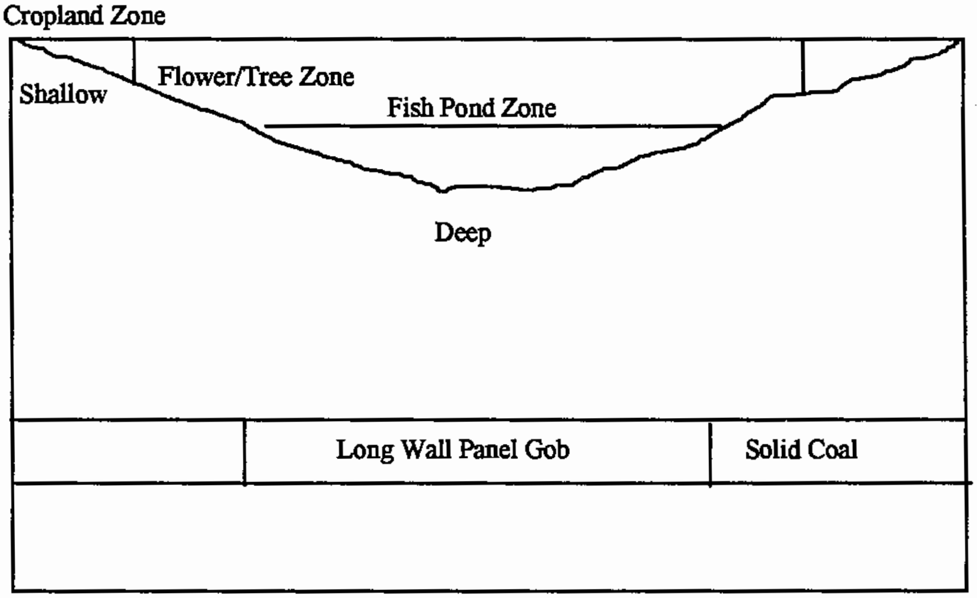


Fig. 2 Diversified Economy According the Situations

We can combine subsidence area control with environmental improvement. Zaozhuang coal mine bureau's Caili coal mine has turned subsidence area into a pretty good park in water. The reclamation area is admired by miners and residents, alike.

## The Principle of Ground Subsidence Prediction Used in Subsidence Control

Most situations of ground subsidence due to underground mining create a continuous subsidence area or trough (Beijing Institute 1981). The trough shape of these subsidence areas follows some rules which can be expressed by mathematical formula. The popular ground subsidence prediction method is by probability integral method. The prediction error is not more than 10%. The subsidence W, tilt T, curvility K, horizontal movement U, and Horizontal deformation E at every point can be calculated out by integral for a certain distribution function.

$$W = m \cdot q \cdot \frac{1}{r} \cdot \int_{y_1}^{y_2} EXP\left[-\pi \cdot \left(\frac{y}{r}\right)^2\right] dy \cdot \frac{1}{r} \cdot \int_{x_1}^{x_2} EXP\left[-\pi \cdot \left(\frac{x}{r}\right)^2\right] dx \tag{1}$$

$$T = \frac{dW}{ds} \tag{2}$$

$$K = \frac{d^2W}{ds^2} \tag{3}$$

$$U = b \cdot r \cdot T \tag{4}$$

$$E = \frac{dU}{ds} \tag{5}$$

In the formulae above,

q ----- subsidence factor;

r ----- main affected radius;

b ----- horizontal movement coefficient;

$x_1, x_2$ ----- lower and upper limit of mining area in x direction;

$y_1, y_2$ ----- lower and upper limit of mining;

ds ----- calculus direction.

When we input mining and geological conditions and other parameters to predict subsidence, the model will produce a contour map, subsidence boundary, subsidence area and subsidence volume. We can judge the depth of water deposit on the basis of the ground water level and topographic map. It provides a scientific basis for subsidence disposal engineering.

## Suggestions for the Future

Since land protection and environmental protection have become basic Chinese policies, comprehensive environmental control in coal mines will be emergent and long term projects for ecological protection in mine areas. Environmental improvement requires both effective policies and advanced technology.

The government should establish more workable and detailed regulations to force the disposal of subsidence areas, refuse and fly ash. The government should set aside funding for specific-purpose of environmental control. The government should also address the combination of responsibilities and rights. Whoever destroys will reclaim and benefit.

Coal mines should organize full time employees to be in charge of the reclamation, combining environmental protection with disposal of mine refuse, fly ash, coal mining under buildings, water bodies, and railways.

Research institutes should focus on developing direct micro-biological method for revegetating coal refuse piles to help solve the difficult problems of coal mine reclamation, and provide the new ways for controlling the pollution of the subsidence, refuse, and fly ash.

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