Disaster types and environmental engineering issues induced by coal mine goafs instability

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Abstract. The disaster and environmental engineering issues induced by coal mine goafs instability have become one of the most important problems threatening safety production and the safety of citizens. Based on the analysis of instability modes of coal mine goafs, the disaster types and environmental engineering issues were researched. The results showed that, firstly, there are six types of instability modes, that is, the goafs instability under the influence of single pillar, geological structures, goafs water, mining disturbance, static load and dynamic load. Secondly, there are two main types of disasters induced by coal mine goafs instability, and one refers to the damages of surrounding buildings and structures, mine earthquake and ecologically environmental damages caused by coal mine goafs instability and ground collapse; the other one refers to equipment damage and workers hazards caused by undermine roof impact. Thirdly, the environmental engineering issues involves three aspects: the living environment, the ecological environment and the working environment. For these three environmental problems, this paper puts forward specific solutions and suggestions.

1. Introduction
According to incomplete statistics, the area of ground collapse caused by coal mine goafs instability in China has exceeded 1000 km\textsuperscript{2}. Nearly 80000 coal mines have been closed since the year 1995. Some of coal mines have been merged into production mines by integrating resources. The other parts have become abandoned coal mines, and the problems of coal mine goafs instability are more serious recently.

Since the year 2009, the authors have carried out series of engineering in ground survey and field investigation, geophysical detection on ground and undermine, goafs instability evaluation, goafs grouting and roof blasting, utilization in midwest China, and the cases had involved more than 600 coal mines. Through theoretical researches and a great deal of practices, the authors have established a systematic understanding for disaster types and environmental engineering issues induced by coal mine goafs instability.

Based on the previous researches, the paper discussed six instability modes of coal mine goafs, analyzed the disaster types, researched environmental engineering issues and provided some solutions.
2. Instability modes of coal mine goafs

Coal mine goafs mainly includes 6 kinds of instability modes. That is, the goafs instability under the influence of single pillar, geological structures, goafs water, mining disturbance, static load and dynamic load.

The instability mode under the influence of single pillar can be described as below: The coal pillars left in the goafs are subjected to loading, creep and oxidation of overburden strata, the support force of the core area of the coal pillars are reduced, and the strength of the coal wall will reduce as well. The roof of the goafs can not be supported effectively. The increase of roof bending moment and the subsidence of cracks will cause goafs instability.

The instability mode under the influence of geological structures can be described as below: Besides the load, creep and oxidation of overburden strata, the interaction between faults or collapse columns and coal and rock mass are also considered. For example, the goafs near the fault are not only influenced by the load of overburden strata, but also influenced by the shear force and friction of the coal and rock mass near the fault surface, and then cause goafs instability.

The instability mode under the influence of goafs water can be described as below: Besides the load, creep and oxidation of overburden strata, the lateral pressure and water erosion effect of goafs water are also taken into account. The influence of the height of water level line in the goafs and the soaking time of the coal pillar will result in the reduction of the strength of the pillar, and the pillar can not effectively support the roof of the goafs, and the subsidence of the roof will cause goafs instability.

The instability mode under the influence of mining disturbance can be described as below: Besides the load, creep and oxidation of overburden strata, the influences of mining disturbance (mining upper, lower or surrounding the coal seam) are also considered. The mining time and the position relationship with the goafs have become the important factors affecting goafs instability.

The instability mode under the influence of static loads can be described as below: Besides the load, creep and oxidation of overburden strata, the ground dynamic loads (such as ground blasting, the vibration caused by the car or train, the continuous vibration caused by the construction of the engineering, etc.), the sudden collapse of the overlying rock (such as the abrupt instability of the roof of the overlying strata, the sudden breaking of the old roof), and the undermine dynamic load (pressure discharging and blasting) are also considered. Under the influence of dynamic loads, the damage of rock mass will cause the deterioration of physical and mechanical properties of coal and rock mass, the stress concentration, the generation and expansion of the crack, and then accelerate the failure of the goafs pillars and roof, and then cause goafs instability.

3. Disaster types induced by coal mine goafs instability

There are two main types of disasters induced by coal mine goafs instability. The first type includes the damages of surrounding buildings and structures, mine earthquake and ecologically environmental damages caused by coal mine goafs instability and ground collapse. The other type includes equipments damage and workers hazards caused by undermine roof impact.

3.1. The disasters induced by ground collapse

3.1.1. Damages of surrounding buildings and structures.

The influence of ground collapse on constructions (structures) is usually transmitted to the superstructures by the foundation of the ground, which mainly affect the surface subsidence and horizontal movement, the surface tilt, curvature deformation, horizontal deformation and so on.
The large area, gentle and uniform subsidence and horizontal movement of the surface are generally have little effect on building structures and will not cause damage to structures. But when the sinking value is very large, especially in the case of high groundwater level, the surface of the basin is accumulated after the subsidence of the surface, so that the construction is submerged in the water, even if it is not damaged, it can not be used.

The surface tilt caused by non-uniform subsidence in the surface movement basin will cause the building structures to be skewed in its scope, as shown in Figure 1. Especially for buildings with small base and high height, such as water towers, chimneys, high voltage towers, etc.. The influence is more serious. The surface tilt will destroy the slopes of roads, railways and pipelines, thus affecting their normal working conditions. The surface tilt deformation also causes the equipment to be skewed and wear more or less.

The magnitude of additional stress caused by curvature deformation is related to the curvature radius of the ground, the physical and mechanical properties of the soil, the characteristics of the buildings. In general, with the increase of radius of curvature, the additional stress on the buildings will be reduced, and the damage will be increased with the increase of the length of the constructions and the increase of the base area.

The surface horizontal deformation is an important factor causing the destruction of constructions. In particular, the buildings of the brick and wood structure has little ability to resist tensile deformation, so it is often forms a crack in the weak part of the building (windows for example) after the tensile deformation. And sometimes there is no obvious crack on the surface, but there are cracks on the wall of buildings. Tensile deformation can break down the pipe or cable. Compression deformation can make the walls of buildings bulge up, and shear or squeeze cracks are formed, so that the doors and windows are deformed and the switches are not working properly.

3.1.2. Mine earthquake disaster.
The mine earthquake induced by sudden collapse of large-scale golfs has become the increasing serious problem in Midwest China. For example, from the year 2004 to the year 2012, only for the mine earthquake level more than 2.0 grads, there are 76 mine earthquake accidents had happened in Yulin City. The typical cases are seen in Table 1.
Table 1. Cases of the mine earthquake induced by suddenly collapse of old coalmine goafs, China.

| Name of coalmine | Area of collapse (m$^2$) | Mine earthquake level (grad.) | Time (y/m/d) |
|------------------|--------------------------|-----------------------------|--------------|
| Shibadun         | 66700                    | 2.8&3.2                     | 2012/06/23   |
| Jinniu           | 46400                    | 2.1                         | 2012/02/19   |
| Changxing        | 559900                   | 2.8                         | 2011/12/07   |
| Saqugou          | /                        | 3.0                         | 2011/03/22   |
| Songjiagou       | 40000                    | 3.8                         | 2008/10/26–27|
| Zhaojialiang     | 120000                   | 3.4                         | 2008/07/31   |
| Bianbula         | /                        | 3.3                         | 2007/08/29   |
| Fuyu             | 260000                   | 4.1&3.7                     | 2005/11/16–17|
| Fenglian         | 120000                   | 3.4                         | 2004/11/29   |
| Majiagaigou      | >20000                   | 3.2                         | 2004/11/21   |
| Gaoshiya         | 200000                   | 4.2                         | 2004/10/14   |

For example, in June 23, 2012, two earthquakes occurred in Shibadun coalmine in Yulin city caused by the goafs collapse. The subsidence area was more than 66700 m$^2$, the step subsidence was intense (see Figure 2). The earthquake in Yulin was obvious. Most of the high-rise buildings were sloshing slightly, and some people were frightened out to the outside. The two earthquakes were detected in the center of China Seismological Network, with magnitudes of 2.8 and 3.2 respectively.

3.1.3. Ecologically environmenal damages.

Aeolian sand landforms are dominated by undulation in Midwestern China. After coal mining, the surface soil has been lost or destroyed, the ecological environment is fragile, the soil conditions are poor, the ecological environment is weak, the disturbance resistance is poor, and it will be more serious when coal mining.

The instability goafs will cause the failure of the overlying rock, which changed the distribution and water content of the aquifers in the mining area, and then cause the change of the hydrogeological conditions, then change the dynamic field of the groundwater. Most of the coal seam mining in Midwestern China mining area is shallow buried deep, overlying thick loose layer of aeolian sand submersible aquifer. After coal mining, the clay aquifers and water storage structures under the cover of aeolian sand will be destroyed, and the groundwater will be gradually drained, and then form a regional groundwater level drop funnel. This will cause great harm to residents' life, ecological environment and sustainable development of energy base.
3.2. The disasters caused by undermine roof impact

3.2.1. Roof disasters.
The roof disasters caused by goafs instability mainly happened under the overlying goafs in the close range coal seam. The rock stratum (the bottom seam roof of the lower coal seam) is affected mostly by the fracture structures and can be regarded as the "block body". The broken rock mass is filled up to the overlying area and can be seen as "bulk". The old roof of goafs are broken and articulated at the top. It can be seen as a "beam" structure. that is, the "block-bulk-beam" structure is easily formed in the roof of the lower coal seam.

Once the roof disasters happen, they will seriously affect the safe mining of the lower coal seam, and even cause the support of the working face to die all.

3.2.2. Impact waves disasters.
Under the action of external force such as mining disturbance, the goafs overlying strata may be cut suddenly, and they will cause rapid movement of the large area roof to the goafs. The air volum in the goafs is reduced, the density increases and a large amount of energy is stored, which has a strong impact on the roadway surrounding airtight projects. In September 6, 2004, the impact waves disaster occurred in No. 2310 roadway of Bao Dian coal mine, Yanzhou Coal Mining Group. The airtight projects of the goafs was destroyed, and caused casualties. It had been considered the main factors were tight and hard overlying rock, activation after cutting by fault, existence of large area of goafs and sudden increase of mining intensity.

4. Environmental engineering issues induced by coal mine goafs instability and some solutions

In reference to the types of goafs instability disasters, the environmental engineering issues involves three espects: the living environment, the ecological envrionme nt and the working environment. For these three environmental problems, this paper puts forward specific solutions and suggestions.

4.1. The living environment
The living environment problems are mainly derived from disasters caused by ground collapse. The damage of the surface constructions and structures directly leads to the deterioration of the living environment, and even the severely damaged houses can not be repaired or rebuilt at all. (Figure 3).

![Figure 3. Damaged house on the surface of goafs.](image)

The sudden collapse of the large area goafs will induce mine earthquake, and the uncertainty of the subsidence position and time in the future probably cause more psychological panic to the residents, and many residents in the mining area have moved away.

Goafs grouting is a powerful way to improve the living environment. Generally speaking, the area of the important buildings on the goafs surface will need grouting and filling; the region of the general buildings will need to be strengthened in time; the area of the large distribution density of the surface
vegetation on the goafs should be backfilled and reclaimed, and the area of mine earthquake often occurs and nearby towns should be locally or wholly filled with materials.

4.2. Ecological environment
The ecological environment problems caused by the goafs instability mainly include the collapse of the strata, the ground collapse, the destruction of the aquifers and the spontaneous combustion of the coal seam caused by the wind leakage from the bottom of the coal mine.

In September 2005, the 3 departments of China jointly issued the *Technical policy for the protection and pollution control of mine ecological environment*, which was used for the ecological environment protection, pollution prevention and control in the planning and design of mineral resources development, mining, mineral processing and waste land reclamation, popularized the application of filling and mining. By the year 2015, the reclamation rate of land reclamation and destruction of mines had reached more than 45%, and the rate of land reclamation by new mines reached more than 85%. In March 2009, the Ministry of land and resources of China issued *The mine geological environment protection regulations*, it is applicable to ground subsidence, fissures, landslides, aquifers and landforms due to mineral resources exploration and mining activities.

In addition, the restoration of ecological environment should also include the utilization of coal mining subsidence area, monitoring and evaluation of goafs instability.

4.3. Working environment
The working environment problems are mainly derived from disasters caused by coal mine impact. Roof disasters and impact waves disasters have harm not only to the workers and equipments (supports, shearers, reloaders, conveyors), but also cause the deterioration of the working environment and affect the safe production of the undermine.

The best way to improve the working environment is to put an end to or minimize the occurrence of roof or impact waves disasters. The roof accidents in the working face, especially the roof accidents induced by the large area goafs, or the impact waves, are generally adopted in stages and steps to reduce the strength of the roof disaster, such as blasting or hydraulic fracturing, and the roadway roof accidents are mostly used (anchor cable, anchor bolt, anchor net and so on) to strengthen support.

5. Conclusions
There are six types of instability modes, that is, the goafs instability under the influence of single pillar, geological structures, goafs water, mining disturbance, static load and dynamic load.

There are two main types of disasters induced by coal mine goafs instability, and one type includes the damages of surrounding buildings and structures, mine earthquake and ecologically environmental damages caused by coal mine goafs instability and ground collapse. The other one includes equipments damage and workers hazards caused by undermine roof impact.

The environmental engineering issues involves three aspects: the living environment, the ecological environment and the working environment. For these three environmental problems, this paper puts forward specific solutions and suggestions.

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