International Journal of Mining Science and Technology 24 (2014) 713–718

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Safety analysis of building foundations over old goaf under additional stress from building load and seismic actions

Xu Ping [a,b], Mao Xianbiao [a,*], Zhang Minxia [b], Zhou Yuejin [a], Yu Bangyong [a]

[a] State Key Laboratory for Geomechanics & Deep Underground Engineering, China University of Mining & Technology, Xuzhou 221008, China
[b] School of Civil Engineering, Henan Polytechnic University, Jiaozuo 454003, China

ARTICLE INFO

Article history:
Received 22 September 2013
Received in revised form 21 January 2014
Accepted 8 March 2014
Available online 27 August 2014

Keywords:
Seismic actions
Additional stress
Old goaf
Foundation
Settlement

ABSTRACT

Additional displacement of the building foundations over old goaf are prone to happen under the additional loads induced by new buildings, weakening-rock mass by mining and seismic actions, which will cause serious damage to the buildings. In order to analyze the safety of the building foundations safety over the old goaf, the structure characteristics of the strata over the old goaf was investigated and the instability conditions of overhanging rocks upon old goaf were also analyzed in this paper. The results indicate that the stability of overhanging rocks is remarkably decreased by the interactions of mining fractures, earthquake force and building load, in addition, the settlement of the foundations over old goaf is increased by the instability of overhanging rocks. According to the location of a new power plant in Yima Mine and its ambient conditions, we defined the influence scope of old goaf via resistivity tomography. Based on the seismic parameters of the construction site, a numerical FLAC^{3d} model of the building foundation under the seismic actions and building load was developed. The numerical results are obtained as follows: the foundation of the main power house meets the requirement of 6° seismic fortification intensity; however, under 7° seismic fortification intensity, the maximum differential settlement of foundation between the neighboring pillars is close to the maximum allowable value, while the seismic fortification intensity reaches 8°, but the safety requirements will not be satisfied.

1. Introduction

Overburden rocks over mining goaf are prone to caving, fracture, bending and damage by the exploitation of coal resources, and the load capacity of the strata above mined areas will be reduced [1,2]. In China, more than 80% of the mines are located in highly seismic fortification intensity regions and old goaf areas are the seismic unfavorable site. However, with the development of the economy, it will be an inevitable trend to build new buildings over the old goaf areas [3,4]. With the interactions of the building load, rocks strength decreasing and seismic actions, the balanced state of overlying strata in old goaf will be damaged and the "activation" of the old mining goaf will appear again [5]. As a result, the additional displacement of the building foundations will be prone to happen, which leads to buildings inclination, cracking, or even collapse.

The stability and the reinforcement measures of building foundations over the old goaf have been researched both at home and abroad for a long time. Many specialized agencies have been set up for the treatment to the old goaf in America. Kim evaluated the safety of building foundations over old goaf by resistivity tomography system in Korea [6]. In China, Zhang and Ma analyzed the stability and deformation laws of building foundations over the old goaf by field tests, similarity simulation experiments and numerical simulation tests [3,7]. Tan and Deng studied the distribution and variation laws for subgrade reaction of the buildings in different zones of mining subsidence areas by means of a mechanics model of the interaction from ground, footing and framework [8]. Guo et al. investigated the foundations of bridge and high voltage power transmission line tower in mining subsidence areas, and introduced a reinforcement scheme [9–11]. However, those above studies are limited to the building foundations affected by building load in mining subsidence areas. Until now, little attention has been given to the safety of new building foundations over old goaf located in seismic fortified areas. The safety of new building foundations over the old goaf is also not involved in *Code for Seismic Design of Buildings* (GB50011-2010) in China. This paper focuses on analyzing the mechanism of overlying strata activation under the interactions of mining, seismic actions and building load. Then the safety of building foundations over the

* Corresponding author. Tel.: +86 18239118501.
E-mail address: hpuxuping@126.com (X. Mao).

http://dx.doi.org/10.1016/j.ijmst.2014.03.030
2095-2686/© 2014 Published by Elsevier B.V. on behalf of China University of Mining & Technology.

old goaf in Yima city has been studied. In this research, the influence scope of old goaf has been clearly defined by the high density electrical resistivity measurement system. Meanwhile, the safety of building foundations over old goaf has been analyzed by a numerical simulation based on seismic data and building load.

2. Mechanism of overlying strata activation by the interaction of mining, seismic actions and building load

Overlying strata and surface movements over goaf have been stabilized after mining for a long time. However, local unstable structures in overlying strata, including cavities, fractures, abscission layers and uncompacted rocks, may exist for a long time. This is a major factor contributing to the "activation" of the old goaf. As a consequence, it is necessary to study the mechanism of overlying strata activation under the interaction of mining, seismic actions and building load, and the stress characteristics of overlying strata in old goaf should be analyzed firstly.

2.1. Structural characteristics of mining overburden in old goaf

The mining overburden is compacted by dead weight and in-situ stress after mining. However, local unstable structures such as cavity, fracture and bed separation may be existent for a long time (Fig. 1). Caving zone, fractured zone, bed separation zone and bending zone will be formed in sequence above the goaf. Caving zone mainly consists of broken rocks, and the subsidence of broken rocks by compaction is the major factor contributing to the "activation" of old goaf in this area. The hinge structure in rock mass above the caving zone is formed under the horizontal thrust and the occlusion friction. Meanwhile, vertical fracture and bed separation are formed in this structure after mining. The "activation" of the old goaf mainly demonstrates the subsidence of fissured rock and bed separation in this area. Rocks in bending zone have slightly effect on the "activation" of the old goaf when it is not affected by special factors such as groundwater drainage. In conclusion, the "activation" of old goaf may appear again, when the local unstable structures are affected by the external forces such as building load, seismic actions, etc. As a result, the safety of building foundations would be affected by the movement of unstable structures in the old goaf.

2.2. Mechanics analysis of uncompacted and overhanging rocks in mining overburden

According to the analysis of mining overburden structure in the old goaf, the local unstable structures leading to the "activation" of the old goaf distribute mainly between the caving zone and the bed separation zone. Layered bond-beam structure has been formed in mining overburden over the old goaf after mining [12]. Local unstable structures such as cavity, fracture and bed separation, etc., distribute in uncompacted and overhanging rocks (Fig. 2).

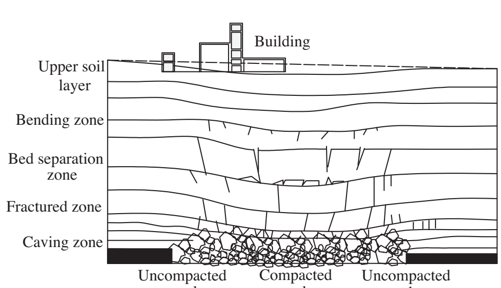

Fig. 1. Structure of overlying strata in old goaf.

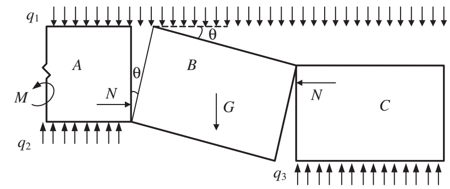

Fig. 2. Stress states of overhanging rocks in strata of old goaf.

Apparently, the movement of the overhanging rock named B mainly affects the "activation" of the old goaf. The stability of the unstable structure is determined by inter-reaction of rock B and rock C. In order to stabilize the overhanging rocks, the rocks need simultaneously to meet two conditions: sliding stability and rotation stability condition shown as in inequalities Eqs. (1) and (2).

$$N \cdot \tan\varphi \geqslant G + q_1 \cdot l \quad (1)$$

$$\eta\sigma_c \geqslant N/\alpha \quad (2)$$

where N is the horizontal pressure; φ the frictional angle between rock blocks; G the dead weight of rock B; q_1 the dead weight from overlying strata; l the length of rock B; N/α the interface average pressure between rock blocks; $\eta\sigma_c$ the extruding strength on the corner of rock blocks.

Many mining areas are located in high intensity seismic regions. In order to analyze the safety of new building foundations in the old goaf, we should take into account not only the building load, but also the seismic force contributing to the "activation" of the old goaf. After building construction in the old goaf, it would induce building load f in mining overburden. Seismic actions produced by the seismic waves propagate. It means that the seismic force may be defined as mutative dynamics [13]. In order to analyze this dynamics, the maximum of dynamics are separated into a horizontal mutative force named T_s and a vertical mutative force named T_p. Then the horizontal seismic force ranges from $-T_s$ to T_s, and the vertical seismic force from $-T_p$ to T_p. Fig. 3 shows the force condition of uncompacted and overhanging rocks in mining overburden. Uncompacted and overhanging rocks affected by building load and seismic force need to satisfy simultaneously the following two conditions: sliding stability condition and rotation stability condition shown as in inequalities Eqs. (3) and (4).

$$(N - 2T_s) \cdot \tan\varphi \geq G + (q_1 + f) \cdot l + T_p \quad (3)$$

$$\eta\sigma_c \geq (N + 2T_s)/\alpha \quad (4)$$

Based on the inequalities Eqs. ((1)–(4)), Table 1 shows the stability conditions of the two kinds of force states. Uncompacted and overhanging rocks affected by mining fracture, seismic force and building load are easier to lead to instability (Table 1). The downslide and rotation force of uncompacted and overhanging rocks increases, but the anti-sliding force drops in this case. Then, the rock mass becomes compact, meanwhile, the abscission layers are suppressed. As a result, the building foundations over mining old goaf sink.

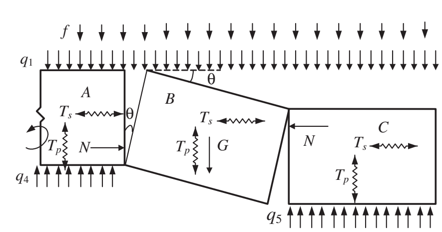

Fig. 3. Stress state of overhanging rocks under mining fracture, seismic actions and building load.