Study on the Influence of Residual Deformation in Old Subsidence Area on the Safety of New Buildings

Shiguo Sun¹, Xinxin Jia¹*, Shuaiying Wei¹ and Jian Xiao²

¹ School of Civil Engineering, North China University of Technology, Beijing 100144, China
² MCC Transportation Group Construction Group Co., Ltd., Hebei Sanhe 06520, China
*Email: 925100223@qq.com

Abstract. The new buildings on the surface of the old subsidence area and the ecological restoration and treatment of the subsidence area are the hot and difficult problems behind the mining of many mining areas. Taking the subsidence area of Laohutai Mine as an engineering example, this paper uses the finite element numerical simulation software to systematically simulate and analyze the stress and deformation of the buildings to be built, raft foundation and foundation soil in different deformation areas. It reveals the deformation and movement law of the building structure at the geometric center area, the maximum negative curvature at the inner edge, the maximum positive curvature at the outer edge and the inflection point of the intersection of positive and negative curvature. The middle zone has the greatest influence on the vertical deformation of the building structure, and the inflection point of the positive and negative curvature has the greatest influence on the inclined deformation of the building structure. The stability of the foundation at four different working conditions is evaluated. Accordingly, it is proposed that reasonable design should be carried out for different regions in architectural design to ensure the safe use of architectural structures.

1. Introduction
With the large-scale development of underground mineral resources, there are more and more surface subsidence areas. The sharp reduction of effective cultivated land and construction land makes the construction ecological restoration and management and reuse of subsidence areas become very important [1-3]. The surface is affected by mining and generates corresponding deformation. After reclamation and backfill, the load size, structural form of the new building and its relative position with the working face are the main disturbance factors for the foundation stability of the old goaf [4-5]. Reasonable selection of building structure and foundation form, master the movement and deformation law of buildings and ground surface in different areas, ensure that the building structure does not occur instability and failure is very important [6-8]. According to the characteristics of surface deformation, this paper selects four representative areas to carry out the planning and design of anti-deformation building structure. The purpose is to analyze the stress characteristics of new buildings in different deformation areas and evaluate the stability of foundation, so as to select safe engineering position and ensure the normal use function of buildings.

2. Project Profile
Laohutai Coal Mine in Fushun City has a mining history of more than 100 years, and a subsidence
basin of nearly 30 square kilometers is formed above the goaf. The abandoned coal gangue is used for backfilling and reclamation as the building foundation. In this paper, four engineering locations are selected as the middle area, the maximum negative curvature at the inner edge, the inflection point of the boundary between positive and negative curvature, and the maximum positive curvature at the outer edge for architectural design (as shown in figure 1). The frame-shear wall structure with strong deformation resistance is selected, and the beam-plate raft foundation is used to coordinate the deformation, so as to analyze the influence of different deformation areas on the safety of buildings. According to the stratigraphic distribution and overall architectural design of the subsidence area of Laohutai, the main mechanical parameters are shown in table 1.

![Figure 1. Building location location diagram.](image)

### Table 1. Main mechanical parameters table of superstructure, foundation and foundation soil.

| Material              | Elastic modulus /GPa | Poisson ratio /μ | Gravity /kN·m⁻² | Shear transfer coefficient under crack opening | Cracks open Shear force under Transfer coefficient |
|-----------------------|----------------------|------------------|------------------|-----------------------------------------------|--------------------------------------------------|
| Beam and plate        | 32                   | 0.2              | 25               | 0.4                                           | 0.1                                              |
| Floor board           | 31                   | 0.2              | 25               | 0.4                                           | 0.1                                              |
| Plate and foundation  | 30                   | 0.2              | 25               | 0.4                                           | 0.1                                              |
| Coal gangue           | 0.0135               | 0.3              | 0.988            | --                                            | 0.1                                              |
| Cretaceous system     | 17.9                 | 0.18             | 25.52            | 0.4                                           | 0.1                                              |
| Granite               | 3.5                  | 0.22             | 29               | 0.4                                           | 0.1                                              |
| Greenish mudstone     | 14.9                 | 0.21             | 24.53            | 0.4                                           | 0.1                                              |

### 3. Study on Influence Characteristics of Different Deformation Zone Location on Buildings

The finite element software ANSYS was used to simulate and analyze the stress and deformation characteristics of the interaction of building structure, foundation and foundation under different engineering site selection conditions, and a three-dimensional grid model (as shown in figure 2) was established. The geometric size of the simulation model was as follows: the depth of foundation soil was 40 m, and the length and width of raft foundation were three times of the length and width of raft foundation, which were 130 m and 42 m, respectively.
Figure 2. Three-dimensional modeling of numerical simulation.

3.1. Influence Attribute of Position Relationship between Deformation Zone and Building

Figures 3 to 5 show the deformation characteristics and settlement curve distribution characteristics of building structures under different working conditions. From the three-dimensional numerical simulation results, when the new building is located at different positions in the subsidence area, the corresponding uneven stress distribution characteristics are generated due to the uneven deformation of the surface. From working condition 1 to working condition 4, the maximum deformation values in the vertical direction are 221.1mm, 166.098mm, 92.971mm and 48.381mm respectively. Among them, compared with the other three conditions, the maximum vertical deformation values of condition 1 increased by 33.1%, 1.38 times and 3.57 times, respectively. Working condition 1 is located in the middle stable area just above the goaf. The overall settlement of the superstructure is relatively uniform, and the building structure is axisymmetrically distributed along Z direction. Therefore, the settlement curve along X direction the characteristics of symmetric distribution. Conditions 2 ~ 4 are located in the uneven settlement area of the ground surface. It can be seen from the displacement cloud map (b, c, d in figure 3) that the left side of the superstructure of the project 2 ~ 4 has a relatively large amount of subsidence. From the settlement curve (figure 4 b, c, d), the overall tilt to the left is serious, the displacement change values are 15mm, 14mm, 11mm, and the relative subsidence decreases in turn.
The inflection point of the deformation curve in figure 4 ~figure 5 is the position of the shear wall, indicating that the existence of the shear wall can alleviate the uneven deformation of the building structure. In order to avoid the large overturning phenomenon of the building, on the one hand, the symmetry of the building design should be considered, on the other hand, the reinforcement design and the increase of the section size of the beam and column can also be considered for the area with large deformation, so as to reduce the relative movement and deformation of the building and ensure the safety of the building within the service life.

Figure 3. Displacement nephogram of building structure under different working conditions.

Figure 4. Settlement curve of building structure along x direction under different working conditions.
Figure 5. Settlement curve of building structure along z direction under different working conditions.

Figure 6–7 show the settlement contours of raft foundation and foundation soil, respectively; when the building is located in different areas of the deformation zone, the settlement displacement distribution characteristics of the raft foundation and the foundation soil are similar to those of the superstructure, and the vertical settlement value does not change much, indicating that the raft foundation coordinates the uneven deformation of the superstructure and the soil. From working condition 1 to working condition 4, the influence range of foundation soil settlement gradually decreases (figure 7), among which the soil settlement in working condition 1 is the largest but the most uniform, and the obvious uneven settlement of the surface from working condition 2 to working condition 4 induces the inclined deformation of the building, which indicates that the surface settlement of different areas in the goaf is quite different under the same building load. The surface tilt of condition 3 at the maximum positive curvature of the outer edge is the most serious, indicating that the surface deformation of the mined-out area is affected in a certain area and has the zoning attribute.
3.2. Evaluation of Foundation Stability Under Different Working Conditions
The results of numerical simulation show that the overall deformation value of the upper building structure in the goaf of Laohutai Mine is shown in table 2, and table 3 is the evaluation standard of the foundation stability of the goaf building [9-10]. The analysis shows that the maximum tilt deformation,
curvature deformation and horizontal deformation of the building structure under working conditions 1 ~ 4 do not exceed the maximum allowable value of the evaluation standard, which conforms to the law of surface deformation characteristics, indicating that the building foundation in the goaf is relatively stable. Among them, the maximum settlement value of condition 1 is -221.1mm, which is within the allowable range, but the value is relatively large, so reasonable building reinforcement should be carried out to slow down the vertical settlement. In condition 3, the inclination deformation of the building structure is the largest and the horizontal deformation is the smallest. In condition 2 and condition 4, the curvature deformation is the largest and the horizontal deformation is also relatively more obvious. Combined with the main damage conditions and simulation results of the buildings around the Tiger Platform, it can be seen that the influence of horizontal deformation on the superstructure is very small, mainly due to the influence of vertical settlement. Therefore, in the construction of new buildings, it is of vital importance to understand the movement and deformation law of the surface in the goaf for the design and reinforcement of buildings.

**Table 2. Deformation values of building structures under different working conditions.**

| Working condition | Maximum settlement /mm | Lateral deformation /mm·m⁻¹ | Oblique deformation /mm·m⁻¹ | Curvature deformation /10⁻³·m⁻¹ |
|-------------------|------------------------|-----------------------------|-----------------------------|-------------------------------|
| 1                 | -221.1                 | 0.16                        | 0.82                        | 0.08                          |
| 2                 | -166.098               | 0.49                        | 1.68                        | 0.13                          |
| 3                 | -92.971                | 0.35                        | 2.56                        | 0.11                          |
| 4                 | -43.381                | 0.52                        | 1.21                        | 0.14                          |

**Table 3. Evaluation criteria of foundation stability of goaf buildings.**

| Evaluation criterion | Settling volume /mm | Surface horizontal deformation /mm·m⁻¹ | Surface tilt /mm·m⁻¹ | Surface curvature /10⁻³·m⁻¹ |
|----------------------|---------------------|--------------------------------------|----------------------|------------------------------|
| ≤300–400             | ≤2                  | ≤3                                   | ≤0.2                 |

4. Conclusion
The settlement deformation, inclined deformation, horizontal deformation and curvature deformation of buildings at different engineering locations are simulated by ANSYS under the combined action of superstructure, box-board foundation and backfill coal gangue foundation. The following conclusions are drawn:

(1) The newly-built 10 - story frame-shear wall residential buildings in the upper central area of the goaf, the maximum negative curvature of the inner edge, the maximum positive curvature of the outer edge and the inflection point area at the junction of positive and negative curvature all meet the construction specifications. But the vertical settlement value of the project position 1 is the largest, which is 3.57 times of the minimum settlement value. The inclined deformation at the 3th position of the project is too large, which is 2.12 times of the minimum inclined deformation value. If the construction is reclaimed, the raft foundation needs to be optimized or the number of building layers needs to be reduced.

(2) In the architectural design should focus on its and The relative position of the working face, the shear wall strength, position selection, beam, column section size of sub-regional rationalization design, while optimizing the design of raft foundation, improve the deformation resistance of building structure, in order to coordinate the foundation caused by uneven deformation tilt deformation, settlement deformation and curvature deformation, to achieve the purpose of protecting the building structure.
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