W.L. FU, L.W. YOU

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# INFLUENCE OF ADDITIONAL STRESS CAUSED BY MINING SUBSIDENCE ON BLAST FURNACE IN METALLURGICAL MINING AREA

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Underground goaf in metallurgical mining area leads to surface subsidence and has destructive effect on blast furnace. This paper studies the influence of underground goaf on blast furnace.The overlying strata and surface subsidence due to the formed gob area after the underground mining led to a different degree of destruction to blast furnace. Hence, blast furnace was modeled to theoretically analyze the additional stress applied to blast furnace body and foundation when withstanding the surface deformation. On this basis, the anti-deformation structure was designed to analyze the influences of Class I - IN surface deformation on the setting of Blast furnace body unit

*Keywords:* blast furnace, additional stress, surface deformation, surface subsidence

## INTRODUCTION

Mineral resources are an important basic energy resource of chinese economy, which plays an important role in ensuring the safety of our national strategic development. The sustained and steady development of mining industry can effectively guarantee the improvement of our national economy. So with the rapid development of the global science and technology, our country metallurgical mine technology is constantly seek new way for development, has got a lot of achievements, has made a great contribution to our country infrastructure, industrial development, iron and steel industry [1-3]. Science and technology is an important engine for the development of the future society, and the key for the effective utilization of mineral resources. It must constantly absorb and accumulate new mining technology and experience at home and abroad, reform and upgrade the traditional mining industry by means of modern science and technology, so as to further promote the development and use of metallurgical mineral resources in our country. Underground mining leads to surface subsidence and damages blast furnace. This paper studies the influence of underground mining on blast furnace. The overlying strata and surface subsidence due to the formed gob area after the underground mining led to a different degree of destruction to t blast furnace The mining subsidence has very complex influences on the blast furnace, which is related to the blast furnace location, nature of the foundation, structural type and size of the blast furnace stress type and deformation value, etc. All the above influencing factors are finally embodied as the blast furnace's additional stress which determines how to optimize blast furnace design in the subsidence area.

W.L. Fu, L.W. You (anshanyouyou0616@126.com) School of applied technology, University of Science and Technology Liaoning, Anshan, China

## DESIGN DATA OF BLAST FURNACE

When the surface deformation is not observed, the design layout of the four-layer office building with a masonry structure is shown in Figure 1. The horizontal axes ① - ⑥ and longitudinal axes A, B, C, D can be embodied in the layout diagram.

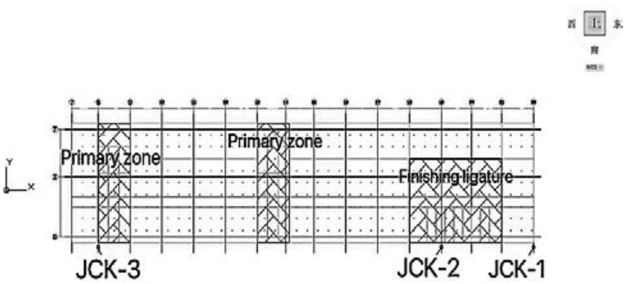



**Figure 1** Settlement monitoring layout

The friction coefficient between the soil and foundation in Anshan Mining Area is f=0,45. The adhesive force per square meter between the oil and foundation is $C$=3$KN$. The total length of contact between the soil and cross section of the designed longitudinal wall foundation is $S$ (m). The bulk density of soil is r=19 $kn/m^3$. The buried depth of the longitudinal wall foundation is $h_0$=1,5 m. The internal friction angle of the soil is p=30°. The calculated length of the longitudinal wall foundation is $L_0$=18 m. The buried depth of the $n^{th}$ cross wall foundation is $h_n$=1,5 m.

To withstand the surface deformation, the wall ring beam is placed on the wall at the window lintel level and the foundation ring beam is placed along the strip foundation. The additional internal force of the building includes $q_{A.D}$=62,95 *kn*/m, $q_{1,6}$=111,82 *kn*/m, $q_{2,5}$=146,1 *kn*/m, $q_{3,4}$=222,7 *kn*/m; and the width of the cross wall foundation includes $D_{1,6}$=900 mm, $D_{3,4}$=1,6 mm, $D_{2,5}$=1,2 mm.

## ADDITIONAL ACTING FORCE UN- DER THE SURFACE DEFORMATION

The maximum axial horizontal force of the longitudinal wall (cross wall) in the direction parallel to the horizontal surface deformation is

$$N_0 = \frac{1}{2}K_0\left\{\left[fq_0 + SC + \frac{1}{2}frh_0^2 \cdot tg^2(45° - 2)\right]L_0 + \right.$$

$$\left. + \sum\nolimits_{n=1}^{m}\left[fq_n + D_nC + \frac{1}{2}rh_n^2 tg^2\left(45° + \frac{\rho}{2}\right)\right]\ln\right\} \quad (1)$$

The horizontal force applied to the longitudinal wall (cross wall) per unit length is

$$N_0' = K_0\left\{\left[fq_0 + DC + \frac{1}{2}rh_0^2 \cdot tg^2\left(45° + \frac{\rho}{2}\right)\right]\right. \quad (2)$$

If the blast furnace withstands Class I - III surface deformation, the maximum additional horizontal force applied to the external longitudinal wall in the axial direction is $N_0$=$K_0$[(31,53+3s)×18+1 858,54]. The maximum horizontal force applied to the cross wall in the horizontal direction perpendicular to the surface deformation is =169,176 $K_0$. The total length of contact between the soil and cross section of the longitudinal wall foundation will be:

$$S = \frac{L_0}{\sqrt[3]{m}} \quad (3)$$

If the building withstands the Class IV surface deformation, the longitudinal and cross walls are designed with the wall ring beam to resist the large surface deformation, except the design similar to the Class I - III surface deformation. The maximum additional horizontal force in the axial direction applied to the external longitudinal wall is $N_0$=[(31,53+3S)×18+1 881,13], while the maximum horizontal force applied to the horizontal wall in the horizontal direction perpendicular to the horizontal surface deformation is =171,12 $K_0$.

The sum of subgrade reactions applied to the longitudinal wall is

$$Fv = \int_0^{L_0}\frac{4V_0}{L^2}\left(\left(L_0 - x\right)xdx = \frac{3}{2}V_0L_0\right. \quad (4)$$

The sum of the upper load P is

$$P = ql_0\,(1+\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_6) \quad (5)$$

Let $\beta_0$=1+λ1+λ2+λ3+λ4+λ5+λ6, then $P$=$\beta_0$q$L_0$. According to the static equilibrium condition, the maximum subgrade reaction is

$$V_0 = \frac{3}{2}\beta_0 q \quad (6)$$

The critical curvature deformation is

$$k_0 = 12\beta_0\frac{q}{bcl_0^2} \quad (7)$$

If the blast furnace foundation stays at the critical state, then the maximum additional bending moment will be applied to the midpoint of the longitudinal wall.

$$M_{\max} = \left(\frac{1}{2}P_1 + \frac{1}{8}qL_0 - \frac{1}{16}V_0L_0\right)$$

$$L_0 = \left(\lambda_1 qL_0 + \lambda_2 qL_0 + \lambda_3 qL_0\right)\frac{L_0}{2} + \frac{1}{8}qL_0^2 - \frac{1}{16}V_0L_0^2 \quad (8)$$

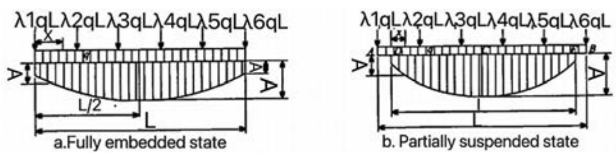
The maximum additional shearing force will approach to both ends of the longitudinal wall

$$Q_{\max} = \left[\lambda_1 + \frac{1}{2} - \frac{1}{2}\beta_0 \pm \left(\frac{1}{9\beta_0} - \frac{1}{6}\right)\sqrt{3\beta_0\left(3\beta_0 - 2\right)}\right]qL_0 \quad (9)$$

If the blast furnace foundation has all embedded state, then

$$M_{\max} = \frac{10\lambda + 1}{32}mqL_0^2 = mM_{\max}$$

$$Q_{\max} = \pm\frac{1}{3}\left(\frac{1}{3\beta_0} - \frac{1}{2}\right)\sqrt{3\beta_0\left(3\beta_0 - 2\right)}mqL_0 \quad (10)$$




a b

**Figure 2** Stress diagram of all embedded and part impending state

If the blast furnace foundation has part impending state, the maximum subgrade reaction is

$$V_0 = \frac{3}{2}\sqrt[3]{m\beta_0 q} \quad (11)$$

The maximum additional bending moment will be applied to the midpoint of the calculated longitudinal wall.

$$M_{\max} = \frac{1}{2}\lambda qL_0^2 + \frac{1}{8}qL_0^2 - \frac{1}{16}V_0 l^2 = \frac{L0}{2}\left(\lambda 1 + \lambda 2 + \lambda 3\right)qL_0 +$$

$$+ \frac{1}{8}qL_0^2 - \frac{1}{16}V_0 l^2 = \frac{L0}{2}\left(\lambda 1 + \lambda 2 + \lambda 3\right)qL_0 +$$

$$+ \frac{1}{8}qL_0^2 - \frac{1}{16}\times\frac{3}{2}\times\sqrt[3]{m}\beta_0 q\left(\frac{L0}{\sqrt[3]{m}}\right)^2 =$$

$$= \frac{qL_0^2}{8}\left[4\left(\lambda 1 + \lambda 2 + \lambda 3\right) + 1 - \frac{3\beta 0}{4\sqrt[3]{m}}\right] \quad (12)$$

The maximum additional shearing force is

$$Q_{\max} = \lambda_1 q L_0 + \frac{1}{2} L_0 q \pm \frac{1}{3} q l \sqrt{1 - \frac{q}{V_0}} - \frac{1}{3} v_0 l \pm$$
$$\pm \frac{1}{3} v_0 l \sqrt{1 - \frac{q}{V_0}} = \lambda_1 q L_0 + \frac{1}{2} L_0 q +$$
$$+ \frac{1}{2} \beta_0 q L_0 \pm \frac{1}{6} \sqrt{\frac{\left(3\beta_0 \sqrt[3]{m} - 2\right)^3}{3\beta_0 m}} q L_0 \qquad (13)$$

## BUILDING DESIGN IN CONSIDERATION OF ADDITIONAL STRESS

The key to the design of t blast furnace in the mining subsidence area is an appropriate configuration for the anti-deformation structure member.

Under the influence of surface curvature deformation, the wall withstands the additional bending moment and additional shearing force.

The reinforced concrete ring beam withstands the normal tension due to the additional bending moment applied to the wall. In the scope of door and window opening, the additional shearing force is applied to the normal tension due to the bending moment of the interlayer horizontal zone.

The masonry structure of the wall body withstands the normal tension due to the additional bending moment applied to the wall body. In the scope of door and window opening, the additional shearing force of the wall body is applied to the normal tension due to the bending moment of the interlayer horizontal zone.

When the additional acting force of the building due to the surface deformation is analyzed, the basically assumed approximate value and different maximum additional acting force are not applied to the same cross section. Hence, the calculated additional acting force shall multiply by 0,8 for reduction when the reinforcement of the ring beam is calculated.

Under the additional bending moment due to the positive curvature deformation, the reinforced concrete wall ring beams (except the foundation ring beam) withstand the normal tension that is applied to the upper wall body. Under the additional bending moment due to the negative curvature deformation, the ring beams (including the foundation ring beam, and except the reinforced concrete ring beam at the cornice or top lintel) withstand the normal tension that is applied to the bottom wall body.

The normal stress that is generated by the additional bending moment due to the above two types of curvature deformation is withstood by the upper or bottom wall body. In the masonry structure of the wall withstanding the normal stress, the capacity of withstanding the normal tension for the ring beam is not considered.

The foundation ring beam mainly withstands the longitudinal force due to the horizontal deformation in the axial direction. Due to the horizontal force in the horizontal direction, the foundation ring beam withstands the longitudinal force due to the horizontal bending moment in the horizontal direction and the horizontal bending moment applied to the bottom inter-layer horizontal zone.

If the blast furnace foundation withstands Class I surface deformation, the corresponding horizontal deformation and curvature deformation are ε=2 mm/m and $k=0{,}2\times10^{-3}$ /m, respectively. If the surface deformation increases one level, the corresponding horizontal deformation and curvature deformation will increase Δε=2 mm/m and $\Delta k=0{,}2\times10^{-3}$/m, respectively. For the design of the four-layer office building with a masonry structure, the top layer and middle layer of the building withstand the maximum longitudinal stress, as shown in Table 1. According to the *Code for Masonry Structure Design*, it is possible to obtain φ=0,8; =0,938 and =0,928 for the top layer; =0,584 and =0,554 for the middle layer, and finally calculate *R*=1,5 *MP*a.

According to the check results, the anti-deformation building shall be considered to design with the ring beam under the Class I surface deformation, instead of setting the constructional column. If the blast furnace foundation withstands Class II and above surface deformation, the bearing capacity of the pier between two windows cannot satisfy the requirements and the anti-deformation building shall be designed with the constructional column.

Table 1 **Geometry elements of reinforced concrete ring beam**

| Ring beams | No. | Sectional dimension | /mm | Bottom elevation /m |
|---|---|---|---|---|
| | | Width | Height | |
| Cornice ring beam | *QL*-1 | 240 | 180 | +11,1 |
| Four-layer floor ring beam | *QL*-2 | 240 | 180 | +8,2 |
| Three-layer floor ring beam | *QL*-3 | 240 | 180 | +5,3 |
| Two-layer floor ring beam | *QL*-4 | 240 | 180 | +2,4 |
| Foundation ring beam | *QL*-5 | 400 | 350 | -2,0 |

## CONCLUSIONS

For the new blast furnace in the mining area, the appropriate structural measures shall be taken based on the predicted surface deformation value to effectively avoid the influence of the surface deformation and solve the underground mining problem. The multi-disciplinary knowledge of the mining subsidence, mechanics of materials, and structural mechanics was applied comprehensively, and a four-layer office blast furnace with a masonry structure in the mining area was selected for model design to study additional stress of the blast furnace under different degrees of surface deformation and then propose different structural layout solutions.

In the design of an anti-deformation structure in the mining area, the material strength shall not be considered specially, because the strength of the framework component and brick wall has a small influence on the anti-deformation capacity of blast furnace. However, the settings of the ring beam and construction column shall be mainly considered in the configuration of the structural element.

The strip foundation is the most common foundation in the surface deformation area. The reinforced concrete ring beam shall be provided for the bedding plane when the strip foundation is configured.

For the Class II and above surface deformation area, the constructional column shall be considered in the structure to improve the entirety and anti-deformation capacity of the building.

The reinforcement ratio of the ring beam shall be improved with the increase of surface deformation level.

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**Note:** The responsible translator for English language is L.W. You, Anshan, China.