The oretical analysis of deformation above roadways excavated in thin coal seam and rock stratification

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Abstract

Deformation induced at roadway's roof depends on many factors such as: rock properties, roadway dimensions, excavation method, stress field existing in rock layers above the roadway, etc. The present paper analyses the relationship between the state of stresses and deformation induced in the roof of roadways, which driven through layered strata, in cases of the roadways excavated in conventional conditions and closed to an exploited area with small width of coal pillar, where pressures in the collapsed area has been stabilized.

Analysis results indicate that the increase in the width of the roadway and strata pressure acting from surrounding rock cause the increase in deflection and strain in rock mass at the roof, and vice versa. Without considering the influence of lateral pressures and with the same roadway's dimensions and strata pressures, deformation estimated at the middle point of the roadway's roof in case of excavating through exploited area is twice larger than that observed in case of excavating in conventional condition.

Due to the different deflection of rock layers, observed deformations are also different depending on rock mass parameters. Small deflection resistance of weak rock mass causes the large deformation and vice versa.

Keywords: Roof stability, Roof abscission layer, layered strata, Numerical model,

1 . Introduction

Thin coal seam and rock stratification is one of the most popular forms during excavation of the roadway to serve the coal mining activity. Rock layer is considered as thick layered when its thickness is greater than 0.4m. The roadways excavated in the thick layered rocks are often relatively stability. Rock strata is considered as thin layers when its thickness is less than 0.4m [1]. The width of serving roadways in coal mining are usually of about 3 ÷ 6m. When the ratio between the thickness of rock layer and the width of serving roadway is less than 1/7, the roadway is designed to excavate through thin-bedded layered rocks [2].

Large deformation at the roof is often observed during excavation of the roadway in thin coal seam/rock stratification, sometimes collapsing arch is also formed. The deformation and collapse height induced above the roadways that are excavated in conventional conditions and closed to an exploited area with small width of coal pillar are not similar. The present paper analyses the relationship between the state of stresses and deformation induced in the roof of roadways, which driven through layered strata, in cases of the roadways excavated in conventional conditions and closed to an exploited area with small width of coal pillar, where pressures in the collapsed area has been stabilized.

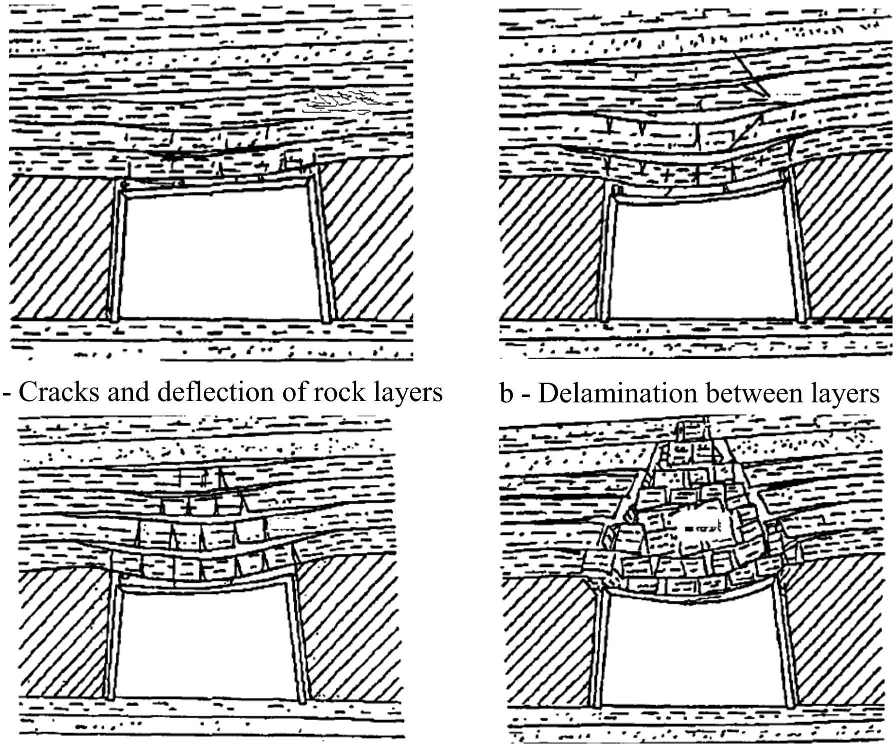
2. Destroying process in the roof of the roadway excavated in thin coal seam and rock stratification

Fig.1 shows the failure process developed above the roof of trapezoidal, rectangular roadways, which are excavated in thin coal seam/rock layers and supported by steel arches.

After excavation, due to thin stratification above the roadway and the influence of excavation, high moisture conditions cause the appearance of cracks, serious swelling deformation and strongly weathered in the rocks surrounding the roadway (Fig. 1, a).

On the other hand, due to installed wedges at the roof of the roadway is not tigh, voids could be existed between the support structure and surrounding rock that leads to the fact that mobilized supporting forces from structure acting on the rock surface are very small. While required supporting forces produced by structure to restricted failure of the surrounding rock at the roof region is about 0.15 MPa [2], their values measured at the roof and side wall of the roadway during construction are only 0.04 MPa and 0.015 MPa, respectively. Consequently, large deflection and development of plastic zone can be observed at the roof of the roadway.

When the deformation of the surrounding rock reaches a certain value, supporting force produced by the structure is gradually increased. If the structure's capacity is not high enough to control the deformation of the rock layers, deflection phenomenon can develop in rock mass at the roof and followed by the delamination of thin rock layers. At the same time, the increase of cracks developed in the rock mass (Fig.1, b) is the reason which cause the decrease in its seft-supporting capacity.



a - Cracks and deflection of rock layers

b - Delamination between layers

c - Crushed rock layer

d - Formation collapsing arch

Fig. 1. Failure process in the roof of the roadway excavated in thin coal seam/rock stratification [2]

When thin rock layers in the roof rock was crumble failure (Fig.1, c) pressures caused by crumbles rocks and by swelling phenomenon between rock layers will act on the roof beams. As the reason, large deformation induced in the roof beams can be predicted.

When the failure is continuous to develop further in the surrounding rock, collapsing arch can be formed (Fig.1, d). The roof beams must support the self-weight of failured rock in this arch. If the supporting capacity of roof beam is not high enough, instability and collapse of the roadway's roof can be predicted.

Observations at some mines showed that cracks can begin to develope in thin rock layers at the roof of the roadway after 8 hours from the excavation time [2]. After 24 hours, steel ribs start to be deformed. After 36-48 hours, deformation at the roof of the roadway reach the maximum value and rock layers at this region fall into instability. It is followed by the formation of collapsing arch. At the final state, deflection induced in the roof beams can reach 100 ÷ 200 mm.

3. Deformation of the roadway's roof with the length is much larger than the width

Fig. 2 shows the model of roadways excavated in conventional conditions. Assuming rock mass in the same layer in the roadway's roof is homogeneous, isotropic and loaded by pressures q. The influence of lateral pressures is ignored. Taking the object of the study is the first rocks layer on the roadway's boundary, the span of the rocks on the exposed roadway's roof is the width of the roadways. Fig. 3 shows the working model of the first rock layer at the roof of the roadway.

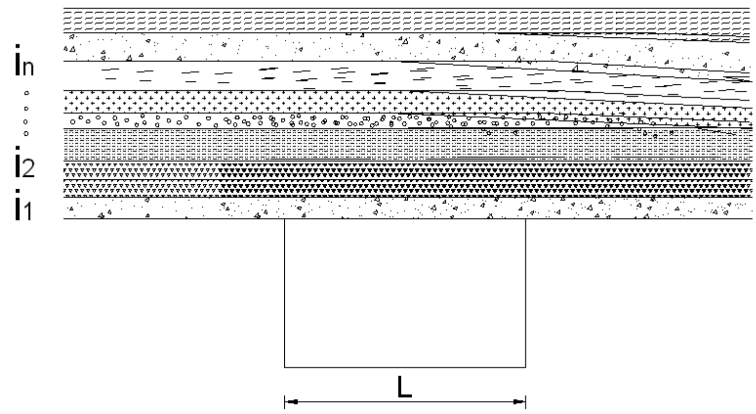


Fig. 2. Model of the roadway excavated in conventional conditions, through thin coal seam/rock stratification

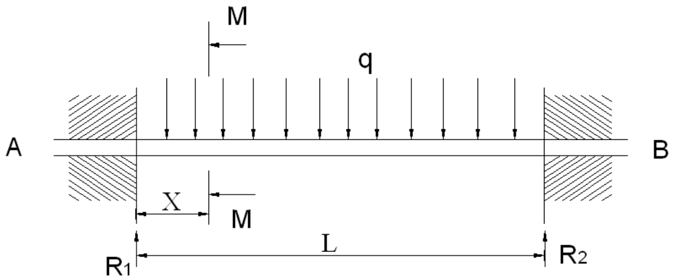


Fig. 3. Working model of the roadway excavated in conventional conditions

3.1. Analysis the bearing capacity of the roadway excavated in conventional condition

In this case, it is reasonable to consider that the first rock layer on the roof of the roadway works as a beam with both clamped ends (Fig. 4).
We have three balancing equations as followed: $\sum F_x = 0$; $\sum F_Y = 0$ and $M = 0$

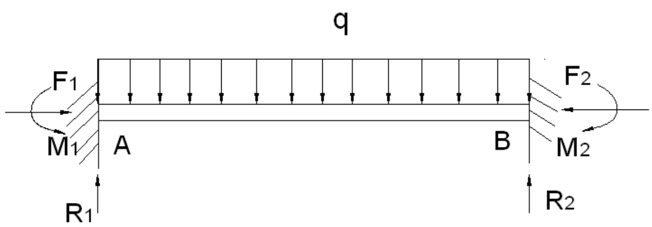


Fig. 4. Force diagrams of the beam with both clamped ends

Due to the symmetry, we have $R_1 = R_2$; $M_1 = M_2$

From Fig. 4 $\sum F_Y = 0$ inferred $$R_1 = R_2 = \frac{qL}{2} \quad (1)$$

Based on the deformation conditions, rotation angle of midpoint of the beam $\theta = 0$ thus, we have:

$$M_1 = M_2 = -\frac{qL^2}{12} \quad (2)$$

At any "M-M" cross-section, based on the balancing equation $\sum F_Y = 0$ The shear force is :

$$Q_X = R_1 - qX = \frac{qL}{2}(1 - \frac{2X}{L}) \quad (3)$$

The largest shear force at two fixed points A and B is

$$Q_{max} = R_1 = R_2 = \frac{qL}{2} \quad (4)$$

Shear force diagram is shown in Fig. 5.

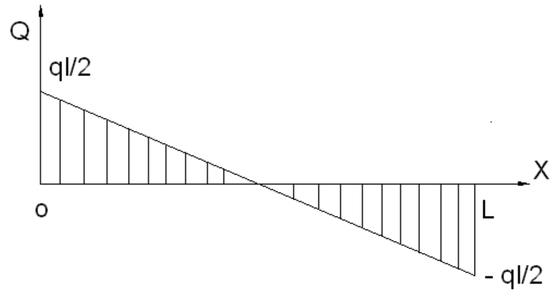


Fig. 5. Shear force diagrams

Based on the balancing equation $\sum M = 0$, bending moment is calculated as followed:

$$M_X = R_1 X - qX\frac{X}{2} + M_1 = \frac{q}{12}(6LX - 6X^2 - L^2) \quad (5)$$

From above formula we can see:

$M_{max} = -\frac{qL^2}{12}$; In midpoint of the beam (X = L/2) , we have $M = \frac{1}{24}qL^2$ (6)

Moment diagrams is shown in Fig. 6.

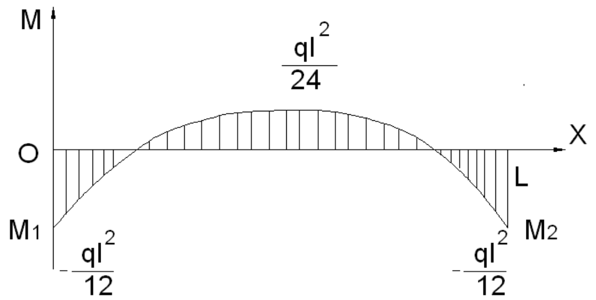


Fig. 6. Moment diagrams

As for the cross section of the beam, deflection of the beam can be calculated by unlimited integration method as follows:

$$EJV = \iint M(x)dxdx + Cx + D \quad (7)$$

Where C, D are constant depending on boundary conditions and continuity conditions.

$$EJV = \iint M(x)dxdx + Cx + D = \frac{q}{12}(Lx^3 - \frac{1}{2}x^4 - \frac{L^2}{2}x^2) + Cx + D \quad (8)$$

Fig .3 shows that the boundary conditions of clamping end are since X = 0; $V_A = 0$; since X = L, $V_B = 0$

Substituting into equation (8) we get C = 0, D = 0. Thus deflection equation is:

$$V = \frac{q}{12EJ}(Lx^3 - \frac{1}{2}x^4 - \frac{L^2}{2}x^2)$$

From deflection equation, it can be seen that the largest deflection is observed at the midpoint of the beam (x = L / 2). The deformation at the midpoint in the roof of the roadway can be estimated using the following equation:

$$V_{mid} = \frac{qL^4}{384EJ} \qquad (9)$$

3.2. Analysis of the bearing capacity of the roadways excavated close to an exploited area with small width of coal pillar

As for roadways with small width of coal pillar, the model of the roadway is presented in Fig.7.

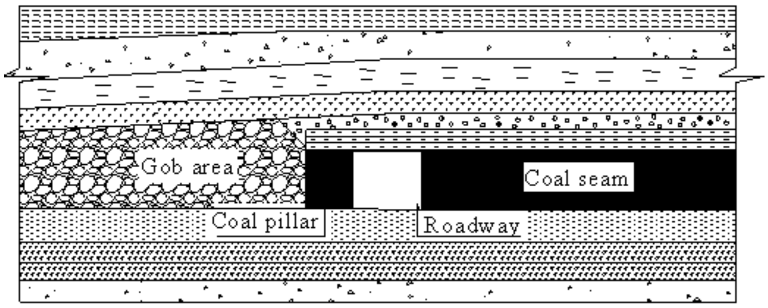


Fig. 7. Model of the roadway with small width of coal pillar

Rock layers in the roof of the roadway in this case works at a beam with only one fixed end, the second end is supported by the coal pillar (Fig.8).

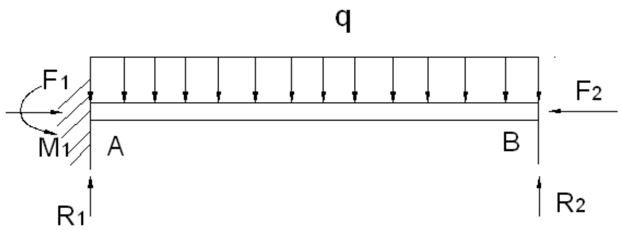


Fig. 8. Force model of one clamped beam

According to Mohr theory [3] relative displacement at point B can be calculated using the following formula:

$$\Delta_B = \int \frac{M(x)M^0(x)}{EI}dx = \frac{1}{EI}(\sum \omega_i M_i^0) = 0$$

Have: $\frac{1}{EJ}\left(\frac{R_2L^3}{3} - \frac{qL^4}{8}\right) = 0$, inferred: $R_2 = \frac{3qL}{8}$

Have : $\frac{1}{EJ}\left(\frac{R_2L^3}{3} - \frac{qL^4}{8}\right) = 0$, inferred: $R_2 = \frac{3qL}{8}$

Based on the static force equilibrium conditions, the reaction force at the clamped end is:

$$M = \frac{qL^2}{8}, \quad R_1 = \frac{5qL}{8}$$

At any "M-M" cross-section, based on balancing equations $\sum F_Y = 0$ we get the shear forces:

$$Q_X = R_1 - qx = \frac{5qL}{8} - qx$$

Shear forces diagrams is shown in Fig.9.

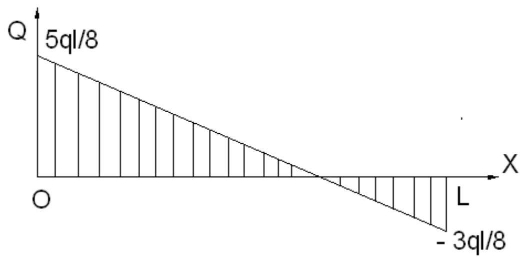


Fig. 9. Shear forces diagrams of roadways with small width of coal pillar

Based on the balancing equation $\sum M = 0$, we have the bending moment:

$$M_X = R_1 X - M - \frac{qx^2}{2} = \frac{5qL}{8}X - \frac{qL^2}{8} - \frac{qx^2}{2}$$

Bending moment diagrams is shown in Fig.10.

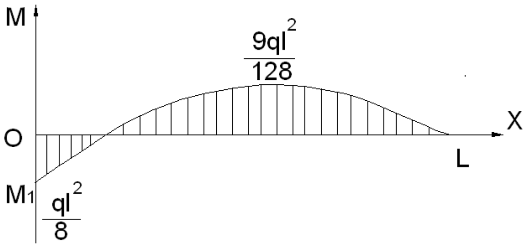


Fig. 10. Bending moment diagrams of roadways with small width coal pillar

Deflection equation is:

$$V = -\frac{qX^2}{48EJ}\left(2X^2 - 5LX + 3l^2\right)$$

From deflection equation we can see the deformation of the midpoint of the beam (x = L/2):

$$V_{mid} = \frac{qL^4}{192EJ} \qquad (10)$$

From equations (9) and (10) we have.

The greater the width (L) and the charge (q), the greater the deflection/deformation and vice versa.

Without considering the influence of lateral pressures, when the roadway's dimensions and strata pressures are the same, deformation at the middle point of the roadway's roof estimated in case of excavating through an exploited area is twice larger than that observed in case of excavating in conventional condition.

Due to the fact that there are many rock layers in the roadway's roof with different properties such as bending stifnees of layers, deflections of different rock layers are not similar. The higher the bending stiffness of the rock layer, the smaller the layer's deflection. Consequently, delamination between rock layers can be observed if the deflection of below layer is higher than that of the above layer. The delaminations value can be estimated as followed:

$$W = V_d - V_{tr} \qquad (V_d > V_{tr}) \qquad (11)$$

Where:
w - Delamination value between rock layers
V_d – Deflection of below rock layer
V_{tr} - Deflection of above rock layer

4. Analyses of deformation induced in the roof of roadways by numerical model

Analyses the relationship between the state of stresses and deformation induced in the roof of roadways, which driven through layered strata, in cases of the roadways excavated in conventional conditions and closed to an exploited area with small width of coal pillar, where pressures in the collapsed area has been stabilized.

4.1. The mechanical parameters and simulation diagrams

The influencing rules in cases of the roadways excavated in conventional conditions and closed to an exploited area with small width of coal pillar are analyzed through numerical simulation software FLAC^{3D} [5] which is suitable for analyzing large deformation problems.

The conditions for simulating model are roadway divided into sandstones, siltstone, claystone coal layers and the dimension of model is 160 x 60 x 60m (width x length x height). Based on the buried depth, the vertical stress applied on the upper boundary of the model is 7,5MPa, and strata inclination 0^0. For bottom, left and right boundary, vertical displacement is fixed. This model adopts Mohr-Coulomb criterion. Mechanical parameters of surrounding rock shown in Table 1.

Roadway dimension is 4 x 3m (width x height), divided in coal seam, on the roadway roof which 8 thin siltstones layered, each layer has thickness is 0.3 m, the analysis diagram shown in Fig. 11 and 12.

Table 1. Mechanical parameters of surrounding rock.

Rock types	Density ρ, g/m^3	Elastic modulus *G*/GPa	Internal friction *f*/°	Conhesion *C*/MPa	Tensile strength *t*/MPa
Sandstones	2,6	3,5	38	20	3.8
Siltstone	2,5	3,4	30	18	3,0
Claystone	2,55	2,9	19	3,6	2,0
Coal	1,6	3,3	17	2	0.6

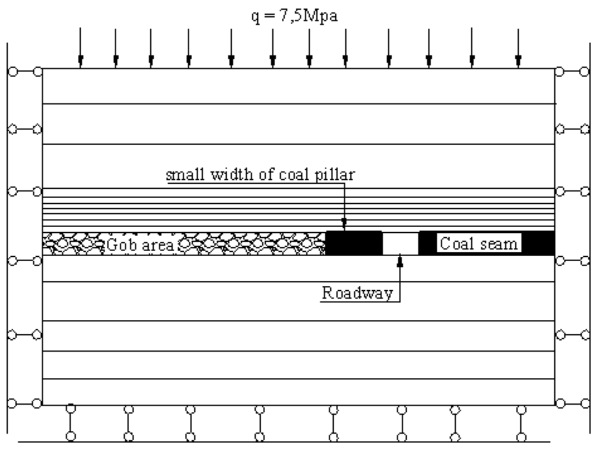


Fig .11.The boundary fixation of numerical model

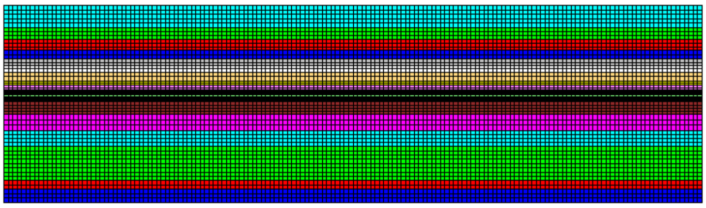


Fig.12. Numerical calculation of model

4.2 Analysis of result and discussion

Displacement of roadway roof in cases of the roadways excavated in conventional conditions and in cases of closed to an exploited area with small width of coal pillar shown in Fig. 13 and 15.

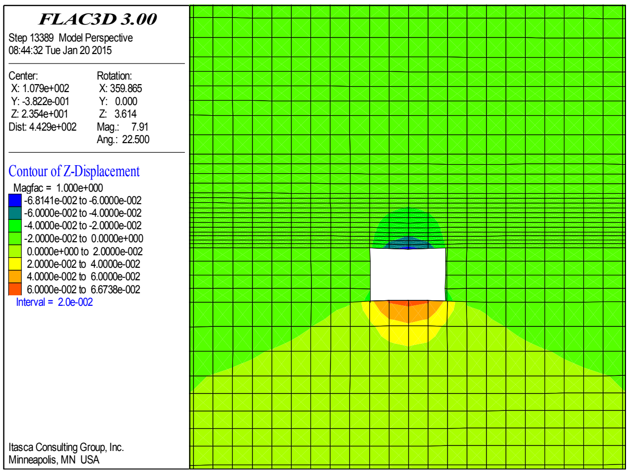


Fig .13. Displacement of roadway roof in cases of the roadways excavated in conventional conditions

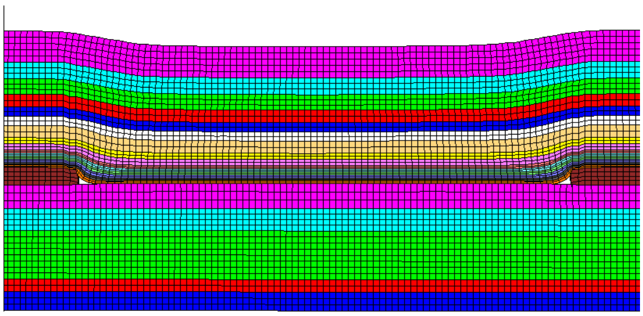


Fig .14. Pressures in the collapsed area has been stabilized

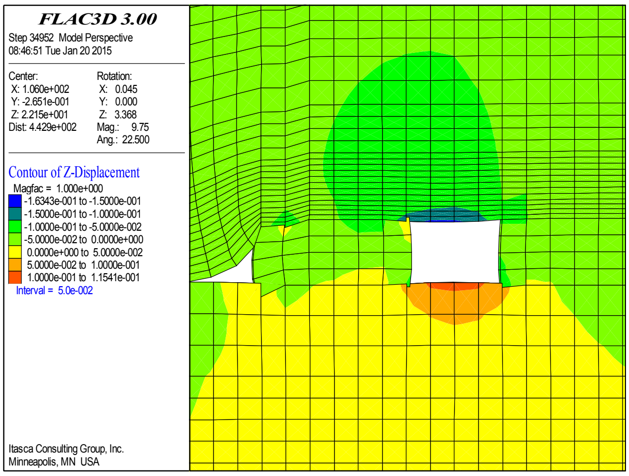


Fig .15. Displacement of roadway roof in cases of closed to an exploited area with small width of coal pillar

According numerical analysis, in cases of the roadway excavated in conventional conditions, the displacement of roadway roof is concentrate stress caused by the span size, especially, for the thin coal seam/rock compound roof, in cases of displacement is 0,068m. In cases of the roadway is excavate close an exploited area with small width of the coal pillar, the displacement developed in the roof of the roadway depends mainly on the concentration of stresses and the span of the roof. This dependence is more important when the roadway is excavated close an exploited area and under thin coal seam/rock layers. The displacement measured in the roof of the roadway in this case is about 0,16m which is approximately twice larger than that determined when the roadway is excavated in conventional conditions.

5 Conclusion

From the study result, some conclusions can be drawn as follows:

Based on the established model, the deformation determined at the middle point in the roof of the roadway excavated in conventional condition can be estimated as followed:

$$V_{mid} = \frac{qL^4}{384EJ}$$

In the roadway excavated close an exploited area with small width of coal pillar, the deformation at the middle point in the roof of the roadway can be estimated as followed:

$$V_{mid} = \frac{qL^4}{192EJ}$$

The greater the width (L) and the charge (q), the greater the deflection/deformation and vice versa.

Without considering the influence of lateral pressures, when the roadway's dimensions and strata pressures are the same, deformation at the middle point of the roadway's roof estimated in case of excavating through an exploited area is twice larger than that observed in case of excavating in conventional condition.

Due to the difference in bending stifnees of rock layers in the roof, deflections of different rock layers are not similar. The higher the bending stiffness of the rock layer, the smaller the layer's deflection.

Delamination between rock layers can be observed if the deflection of below layer is higher than that of the above layer.

Analytical and numerical results obtained in this study indicated the higher instability of the roadway excavated close an exploted area with small width of coal pillar and under thin rock layers on the roof, compared to that predicted in case of the roadway excavated in conventional conditions.

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