Study on Resources Assessment of Coal Seams covered by Long-Distance Oil & Gas Pipelines

Bing Han, Qiang Fu *, Wei Pan and Hanfang Hou
China National Institute of Standardization, Beijing 100191, China

*Corresponding author e-mail: fuqiang@cnis.gov.cn

Abstract. The assessment of mineral resources covered by construction projects plays an important role in reducing the overlaying of important mineral resources and ensuring the smooth implementation of construction projects. To take a planned long-distance gas pipeline as an example, the assessment method and principles for coal resources covered by linear projects are introduced. The areas covered by multiple coal seams are determined according to the linear projection method, and the resources covered by pipelines directly and indirectly are estimated by using area segmentation method on the basis of original blocks. The research results can provide references for route optimization of projects and compensation for mining right..

1. Introduction
With the rapid development of the national economy, the construction scale of high-speed railways, expressways, long-distance oil/gas pipelines, main water canals and other large linear projects has been expanded ceaselessly. During route selection, mineral resources are avoided as much as possible. Limited by the social environment, human activities, geological disasters and other factors, however, the land used for the construction of long-distance linear projects inevitably passes through the mineral resources involving in ore fields, mineral prospecting rights and mining rights etc [1-4]. For the purpose of balancing the construction of projects and the protection of resources, not only protecting and rationally utilizing mineral resources but also facilitating the smooth construction of projects, it is necessary to fully demonstrate the rationality, economical efficiency and necessity for the resources to be covered by construction projects under the condition that the resources to be occupied and covered by the construction projects are precisely verified to avoid the geological disasters of the planned projects during the later development of mineral resources possibly caused or worsened by the mine gobs, which has become a critical issue in evaluating and verifying the mineral resources to be covered. To take a large coal mine prospecting right to be covered by a planned gas pipeline in west China as an example, the paper discusses the method for determining the evaluation scope of mineral resources to be covered by the land used for the construction of linear projects, the method for estimating the resources/reserves, and method for selecting parameters etc.

2. Project overview
Central Asia is rich in oil and gas resources. Due to its adjacency to China, it is one of the important strategic regions for China to realize the replacement of oil/gas resources. The planned gas pipeline is from the natural pipeline resources in Central Asia to markets in the regions around Bohai Sea and in Northeast China, and it is an important part for the perfection of China’s strategic channels in natural gas import. The designed pipeline route is from Ulugqat County, Kizilsu Kirghiz Prefecture, Xinjiang...
Uygur Autonomous Region to Shanshan County, Turpan Prefecture. The pipeline route is generally in NW-SE direction, passing through 16 counties and cities of Artux, Maralbexi, Aksu, Korla, Toksun and Turpan etc. The total length is 1,456km. The land used for the Project includes permanent land occupation for station, valve chambers and surrounding ancillary facilities as well as temporary land occupation for construction belts, construction roads, pipe stacking area and spoil area etc. The designed route of the planned pipeline overlays a large coal mine with prospecting right in Turpan Prefecture. According to the geological prospecting report on this prospecting right, the coal-bearing strata in the explored area are Middle Jurassic Xishanyao Formation and Lower Jurassic Badaowan Formation. Nine exploitable coal seams are investigated in the explored area, the thickness of major exploitable coal seams is variable to a certain extent, and other coal seams are simple in structure, with obvious features in combination.

3. Determination of areas to be covered

As for the determination of the mineral resources to be covered by long-distance linear projects of long-distance pipeline etc., lots of factors shall be taken into account, such as pipe protection ranges, pipe rack enclosing belts and safety pillars. The pipe protection range is the premise and basis on which the mining right inquiry, data collection and field investigation regarding the resources to be covered by construction projects are carried out. Pursuant to the Law on the Protection of Oil and Gas Pipelines of the People’s Republic of China (Presidential Decree No. 30), in combination with the scope of the planned project, the geological conditions along the route, the attributes of occurring mineral resources and the exploitation methods, the protection range of this gas pipeline is determined to be the areas within 200m away from both sides of the center line of the pipeline. Meanwhile, according to the standards for building protection classification [5], steel gas pipelines are of Class III protection. Therefore, the enclosing belt is expanded outward for more 10m at two sides of the protection range of the pipeline.

In respect of the buildings (structures) set for protecting coal pillars, the scribe projection method can be used according to the displacement angle of the mine to design the protected coal pillars obliquely crossing the coal seam courses at the boundary of the protected coal pillars. Firstly, according to the pipeline inflection point, several vertical sections are arranged along the pipeline axis as shown in the Fig. 1(a); secondly, at the intersection point between each vertical section and the boundary of the enclosing belt at two sides of the pipeline where the line delineated according to the displacement angle in the loose bed, the displacement angle in the uphill direction and the displacement angle in the downhill direction intersects with the elevation at the coal seam floor, the delineated range vertically projected on the ground is taken as the range to estimate the resources to be covered. For the resources to be covered in case of multiple seams, the boundaries at both side determined according to the lowest seam is the maximum range to be covered, as shown in Fig. 1(b). The resources within the lineation of the displacement angle are defined as the resources to be directly covered while those between the lineation of the displacement angle and the boundary at both sides are defined as the resources to be indirectly covered. Thirdly, the covered range determined according to scribe projection method (hereinafter referred to as the projection value) is compared with the pipe protection range (200m at both sides respectively), the larger value should prevail: if the projection value is <200m, then the covered range =200m; if the projection value is >200m, then the covered range should prevail. Fourthly, the assessment range of resources determined in the geological exploration report is superimposed on the covered range, and the resources in the overlapping range are the resources to be covered.
4. Assessment of reserves to be covered

4.1. Assessment method
The coal seam pitch in the area assessed is generally within 1~10°. According to applicable specifications [6], the horizontal projection drawing is taken as the traced drawing for resources in coal seams, and the resources assessment drawing is referred to from the original geological exploration report. For the assessment of covered reserves, on basis of the contour line of coal seam floors and resources assessment drawing in the original report, the scribe projection method is used to line out the overlaying range for the planned pipeline according to the displacement angle, and it is superimposed on the resources assessment drawing. The area is segmented on the basis of the original ore blocks by means of overlaying range boundary to divide the direct overlaying and indirect overlaying.

The formula to estimate coal resources according to geological block method is as follows:

$$Q = \sum_{i=1}^{n} S_i \times M_i \times D / \cos \alpha_i$$  \hspace{1cm} (1)

Wherein
- $Q$ – resources in coal seams, t;
- $n$ – number of blocks;
- $S_i$ – horizontally projected area of ore block, m$^2$;
- $\alpha_i$ – dip angle of coal seam block;
- $M_i$ – thickness
- $D$ – apparent relative density of coal seam, t/m$^3$.

4.2. Overlaying boundary
Firstly, draw a straight line along the angel $\varphi$ in the loose bed to determine the protected width on the bedrock surface, as shown in Fig. 1(b). The line starts from the boundary of the pipe enclosing belt (10m at both sides respectively), and ends at the bedrock surface. The formula is as follows:

$$S = h \cdot \cot \varphi$$  \hspace{1cm} (2)

Wherein,
- $S$ – protected width on the bedrock surface, m;
- $h$ – thickness of loose bed, m;
Φ – displacement angle of loose bed.

Then, draw straight lines in the rockbed along the displacement angles $\beta'$ and $\gamma'$ respectively on the oblique section. The intersection points between straight lines and coal seam floor are the upper and lower boundaries of the protected coal pillar on this section. The formula is as follows:

$$
\cot \beta' = \sqrt{\cot^2 \beta \cos^2 \theta + \cot^2 \delta \sin^2 \theta}
$$

$$
\cot \gamma' = \sqrt{\cot^2 \gamma \cos^2 \theta + \cot^2 \delta \sin^2 \theta}
$$

Wherein,

$\gamma$ – rock stratum displacement angle in downhill direction;

$\beta$ - rock stratum displacement angle in uphill direction;

$\delta$ - rock stratum displacement angle in the course;

$\theta$ - acute angle between the enclosing belt and the coal seam course.

### 4.3. Computing Parameters

According to the geological exploration report, the land used for the construction of the planned pipeline overlays 13 coal seams, including 9 exploitable seams numbered from M1 to M9. With software MapGis, the thickness ($h$) of loose bed and the vertical depth ($H$) from coal seams to the ground surface at vertical sections can be obtained from the prospecting line profile. See Tab. 1 for details.

| Vertical section | Thickness of loose bed, $h$ | Vertical depth of coal seam, $H$ |
|------------------|-----------------------------|---------------------------------|
|                  | M1  | M2  | M3  | M4  | M5  | M6  | M7  | M8  | M9  |
| A-A'             | 151.60 | 714.15 | 805.38 | 815.99 | 827.15 |
| B-B'             | 131.73 | 625.29 | 714.93 | 724.75 | 736.29 | 1013.37 | 1031.29 |
| C-C'             | 131.66 | 518.99 | 612.47 | 619.98 | 630.47 | 887.39 | 908.89 | 921.89 | 967.39 | 986.41 |
| D-D'             | 117.81 | 244.93 | 327.09 | 331.64 | 344.00 | 571.90 | 595.61 | 603.06 | 640.71 | 665.8 |
| E-E'             | 37.55 | 265.77 | 275.07 | 281.07 | 329.63 | 357.29 |

Tab. 2 and 3 provide the value range [6] for loose bed displacement angle $\phi$ and surface displacement angle differentiated according to overlying strata characters. According to the geological exploration report, the thickness of the quaternary loose bed in this exploration area is 15~208m, containing no water. The displacement angles $\phi$ are determined to be 50° ($h<40$m), 55° (40m $\leq h \leq 60$m) and 60° ($h>60$m) respectively. Rock strata displacement angles are determined to be $\delta=\gamma=70°$ and $\beta=\delta-0.7\alpha$. Values of $\theta$ and $\alpha$ are measured and determined from the contour map of the coal seam floor and the prospecting line profile according to the positions of different vertical sections.

| Displacement angle, $\phi$ (°) | Dry and water-free | Highly watery | Containing quick sand bed |
|-------------------------------|--------------------|---------------|--------------------------|
| Thickness of loose bed, $h$ (m)| 50                 | 45            | 30                       |
| $< 40$                        |                    |               |                          |
| $40$–$60$                     | 55                 | 50            | 35                       |
| $> 60$                       | 60                 | 55            | 40                       |

| Nature of overlying strata | Major lithology | Displacement angle (°) |
|----------------------------|-----------------|------------------------|
|                            | $\delta$       | $\gamma$               | $\beta$               |
|                            |                 |                        |                        |

Table 1. Thickness of loose bed and vertical depth of coal seams (Unit: m).

Table 2. Loose bed displacement angle, $\phi$.
Hard Mesozoic strata greywacke and hard limestone prevailing, with arenaceous shale, shale and diabase

Medium hard Mesozoic strata medium hard sandstone, limestone and arenaceous shale prevailing, with weak conglomerate, tight marlstone and iron ore

Weak Cenozoic strata arenaceous shale, shale, marlstone and loose beds such as clay and sandy clay prevailing

*α is the dip angle of coal seam.

Table 4. Scribe projection parameters for vertical sections.

| Vertical section | dip angle of coal seam | Displacement angle of loose bed | Displacement angle of the course | Displacement angle of uphill direction | Displacement angle of downhill direction | Angle between enclosing belt and coal seam strike | Displacement angle of oblique section |
|------------------|------------------------|---------------------------------|----------------------------------|----------------------------------------|------------------------------------------|----------------------------------------|-----------------------------------------------|
| A-A’             | α: 10                  | ϕ: 60                           | δ: 70                            | β: 63                                  | γ: 70                                    | θ: 60                                   | β': 67.9                                     |
| B-B’             | α: 10                  | ϕ: 60                           | δ: 70                            | β: 63                                  | γ: 70                                    | θ: 60                                   | γ': 70.0                                     |
| C-C’             | α: 10                  | ϕ: 60                           | δ: 70                            | β: 63                                  | γ: 70                                    | θ: 60                                   | β': 68.2                                     |
| D-D’             | α: 9                   | ϕ: 50                           | δ: 70                            | β: 64.4                                | γ: 70                                    | θ: 70                                   | γ': 69.1                                     |
| E-E’             | α: 8                   | ϕ: 50                           | δ: 70                            | β: 64.4                                | γ: 70                                    | θ: 78                                   | γ': 69.7                                     |

On basis of the prospecting line profile, the upper and lower boundaries of coal seams in different sections are determined by delineating along the displacement angles (β’ and γ’) in the oblique section. This value can be directed read from the drawing. Fig. 2 provides two vertical section views at the position of B-B’ and D-D’. See Tab. 5 for the statistics of overlaying boundaries of coal seams.

Table 5. Overlaying boundaries of different coal seams in vertical sections (Unit: m).

| Coal seam | A-A’ overlaying boundary | B-B’ overlaying boundary | C-C’ overlaying boundary | D-D’ overlaying boundary | E-E’ overlaying boundary |
|-----------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Uphill    | Downhill                 | Uphill                   | Downhill                 | Uphill                   | Downhill                 |
| M1        | 339.83                   | 310.43                   | 299.58                   | 274.26                   | 252.12                   | 235.31                   | 142.68                                      | 130.27                                      |
| M2        | 377.76                   | 342.86                   | 334.85                   | 308.00                   | 287.45                   | 270.53                   | 175.88                                      | 158.52                                      |
| M3        | 383.62                   | 345.52                   | 339.84                   | 310.67                   | 290.73                   | 273.11                   | 177.64                                      | 160.05                                      |
| M4        | 387.51                   | 350.07                   | 344.38                   | 314.89                   | 294.44                   | 277.26                   | 182.71                                      | 164.18                                      |
| M5        |                         |                          | 451.38                   | 420.45                   | 389.92                   | 376.06                   | 274.22                                      | 243.99                                      |
| M6        | 458.84                   | 426.71                   | 398.23                   | 383.86                   | 384.45                   | 350.27                   | 143.29                                      | 134.39                                      |
| M7        | 403.22                   | 388.79                   | 387.40                   | 353.83                   | 387.40                   | 353.83                   | 143.61                                      | 136.49                                      |
| M8        | 420.53                   | 405.87                   | 320.28                   | 266.68                   | 163.73                   | 153.51                   |                                              |                                              |
4.4. Overlapping of assessment range

According to the geological exploration report, the land used for the construction of the planned pipeline overlays 13 coal seams, including 9 exploitable seams numbered from M1 to M9. With software MapGis, the thickness (h) of loose bed and the vertical depth (H) from coal seams to the ground surface at vertical sections can be obtained from the prospecting line profile. See Tab. 1 for details.

On the principle that the larger value should prevail, all values less than 200 m as indicated in Tab. 5 are replaced with 200 m. Then, the finally covered boundary is projected on the plan view, and boundary points are connected to delineate the overlapping range. The overlapping range is superimposed on the coal resources assessment drawing. The segmented blocks within the overlapping range are coal resources to be covered. Fig. 3 indicates the overlapping drawings of the resources in the coal seams M2, M4 and M6, which are covered by the planned pipeline. The net region therein indicates the direct overlapping, and the shadow area indicates the overlying coal resources which are indirectly covered within the vertical projection of the boundaries at both sides of the lowest coal seam.

According to the overlapping map of resources to be covered, the planned pipeline directly overlays 108.54 million tons of coal resources including 32.16 million tons of 332 resources, 61.89 million tons of 333 resources, and 14.19 million tons of 334 resources; indirectly overlays 12.10 million tons of coal resources including 770,000t of 332 resources, 10.11 million tons of 333 resources, and 1.22 million tons of 334 resources. Tab. 6 indicates the assessment results of coal resources to be covered by the planned pipeline.

**Figure 2.** Vertical sections of coal seams.
Table 6. Assessment results of coal resources to be covered (Unit: 10,000 tons).

| Coal seam No. | Direct overlaying | Indirect overlaying |
|---------------|-------------------|---------------------|
|               | 332               | 333                 | 334?                | 332 | 333 | 334? |
| M1            |                   |                     |                     | 281 | 146 |      |
| M2            | 1862              | 438                 | 734                 | 5   |      |      |
| M3            | 347               |                     | 124                 |     |      |      |
| M4            | 262               |                     | 76                  |     |      |      |
| M5            | 613               | 352                 | 308                 | 48  | 28  | 22   |
| M6            | 173               | 634                 | 257                 | 18  | 36  | 15   |
| M7            | 187               | 124                 | 135                 | 11  | 7   | 7    |
| M8            | 336               |                     | 6                   |     |      |      |
| M9            | 2243              | 2272                |                     |     |      |      |
| Total         | 3216              | 6189                | 1419                | 77  | 1011| 195  |

Figure 3. Overlapping for resources assessment of multiple coal seams.
5. Conclusion
The protection range of the gas pipeline determined in this paper is 200m at both sides of the center line of the pipeline. In respect of long-distance pipelines, the protection range is not a fixed value, and it depends on the different requirements in different regions. To determine the protection range, lots of factors such as the geological conditions along the pipeline, regional safety level, pipeline transmission pressure, pipeline crossing areas and the ground facilities such as station valve chamber shall be taken into account, and applicable laws, regulation and local ordinances shall be referred to. For the coal resources in multiple seams, as the boundaries of the protected coal pillars in each seam expand gradually along with the extension of the mine displacement angle, both sides of the boundary of the lowest coal seam should be taken as the maximum overlaying range for the assessment of the resources to be covered. As a result, in addition to the direct overlaying of pipelines on each coal seam, the mining effect of the lowest coal seam on other overlying seams, i.e. indirect overlaying, should also be taken into account.

For the industrial index, category determination and block division etc. involved in the assessment of the reserves to be covered, the data in original Geological Exploration Report is followed. In addition, all assessment parameters remain unchanged except the area to be estimated that might change for the boundary segmentation of the areas to be covered. Therefore, the assessment of the resources to be covered in the same areas is consistent with that in the original report.

Acknowledgments
This work was financially supported by President Funding of China National Institute of Standardization (242017Y-5302).

References
[1] Liu Xiaodong, Zuo Shenghua, Cao Husheng, “Determination of the protective coal pillar in pressed mineral resources estimation”, Shaanxi Coal, no. 1, pp.89-91, 2015.
[2] Ding Pengtao, “Estimation of overlaid coal resources in mine construction”, Geology of Shaanxi, vol. 32, no.1, pp.92-95, 2014.
[3] Li Zaixing, Xu Wei, Peng Ni, Luo Shaoyong, Qi Jianbao, “Study on reserve estimation of the overlaid mineral resource - a case study on overlaid mineral resource on the sanmenxia - xichuan highway”, Ground water, vol. 36, no.3, pp.148-160, 2014.
[4] Dai Shuihong, Cai Changfa, “Assessment of Road Engineering Constructed Over Mineral Resources between Mengzi and Caoba in Yunnan”, Acta Geologica Sichuan, vol. 35, no.2, pp.315-317, 2015.
[5] Jin, Liansheng, Mu Jinsu, Specifications for Coal Pillar Preservation and Compressed Coal Mining for Buildings, Water Bodies, Railways and Main Shafts. Coal Industry Publishing House, China, 2000.
[6] Walcot Gibson, The Geology of Coal and Coal-Mining, Forgotten Books, USA, 2015.
[7] Wang Weidong, Li Yanping, “Error and correction of coal resources/reserves estimation by geological block methods”, Coal Geology & Exploration, vol. 42, no.5, pp.1-3, 2014.
[8] Zhang Shihu, “Application of displacement angle in assessment of mineral resources below constructed projects”, Resources Environment & Engineering, vol. 28, no.3, pp.326-331, 2014.
[9] Gao Zaoqi, Gao Weiming, “Influence factors of construction projects constructed over mineral resources”, Resources Environment & Engineering, vol. 29, no.4, pp.499-502, 2015.