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# Surface Subsidence Analysis Due to Longwall Underground Coal Mining Method in PT. Gerbang Daya Mandiri, Tenggarong, East Kalimantan

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PT Gerbang Daya Mandiri will apply longwall underground coal mining method on its mine site, which is located in Kutai Region. Hence, surface subsidence would potentially occur at the surface area and consequently subsidence analysis including the likelihoods of subsidence profile, maximum value of subsidence and area of surface subsidence is needed. The analysis reveals that the maximum value that is calculated using empirical formulae of the UK National Coal Board differs to that of numerical analysis using distinct element method and the later also suggests that the coverage area of surface subsidence would be $1.7 \times 10^6$ m$^2$.

## 1. Introduction

The mine site of PT Gerbang Daya Mandiri (GDM) is located in Kutai Kertanegara, East Kalimantan, Indonesia (Fig. 1). GDM coal consists of several seams which are part of Kutai Basin Coal with average dip of 3°-13° and coal seam thickness varies from 0.1 to 9.8 meters. Despite open pit coal mine of GDM has been operating since October 2009, longwall underground coal mine method however should now be applied to keep the mine in operation and this is due to environmental constraints.

It has been well accepted that the application of longwall underground coal mine may expect surface subsidence. Since most of the surface area is made use of farm land, rice field and settlement it is therefore important to carry out a comprehensive research of subsidence analysis. The research embraces prediction of maximum value of subsidence, subsidence profile and the area of surface subsidence from which potential remedial action could be prepared in early stage. In order to gain a complete picture of the subsidence analysis, the research is carried out in panel AF4 & AF5 and panel NB F3 & NB F4 on A seam and BC upper seam respectively (Fig. 2).

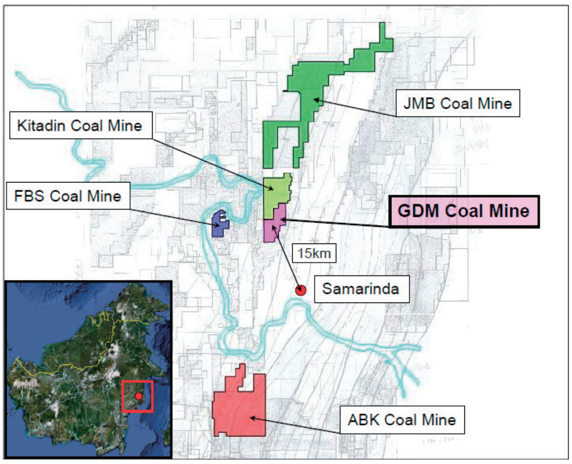


**Fig. 1** Location of GDM Coal Mine[1].

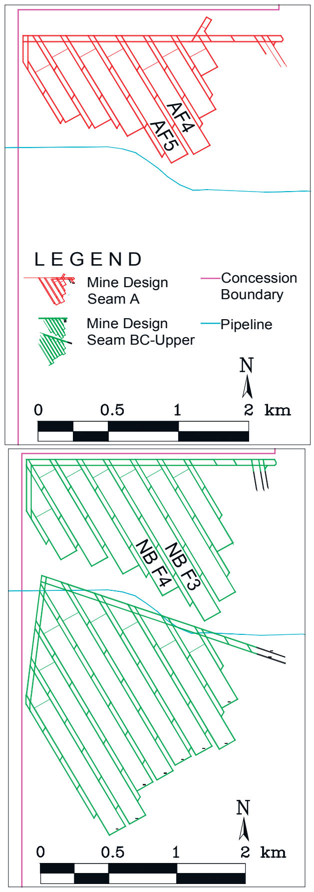


**Fig. 2** Mine design of AF4, AF5, NB F4, and NB F4 Panel[1].

## 2. Panel dimension and site investigation

The geometry of panels AF4, AF5, NB F3 and NB F4 is given in Table 1. The lithology of the mining area at GDM is dominated by sandstone and claystone as can be seen in the bore-log of NED 02 borehole (Fig. 3). Highwall side of former open pit mine which shows interburden between seam 1, seam A and seam B is shown in Fig. 4.

Laboratory tests on rock samples obtained from the NED-02 borehole were conducted to determine the physical and mechanical properties and they are available in Table 2. Whereas the mechanical properties of the material of the bedding planes such as cohesion and internal friction of angle are given in Table 3.

The subsidence analysis applies both numerical and empirical methods and uses the data of Tables 2 and 3 as well as data provided by the GDM Geotechnical Department.

**Table 1** Panel geometry[1)]

| Seam | Panel | Tilt (°) | Width (m) | Height (m) | Length (m) | Depth (m) |
|---|---|---|---|---|---|---|
| A | A F4 | 8.7 | 140 | 2.8 | 730 | 200 |
| | A F5 | 8.7 | 140 | 2.8 | 920 | 235 |
| BC *upper* | NB F3 | 8.1 | 140 | 2.8 | 1250 | 245 |
| | NB F4 | 8.1 | 140 | 2.8 | 1030 | 285 |

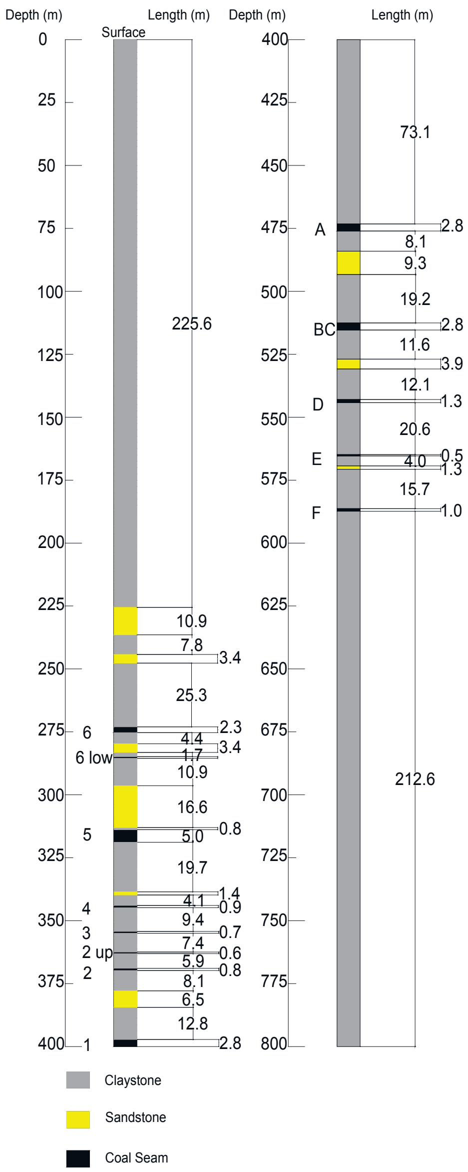


**Fig. 3** Bore-log of NED 02 Borehole.

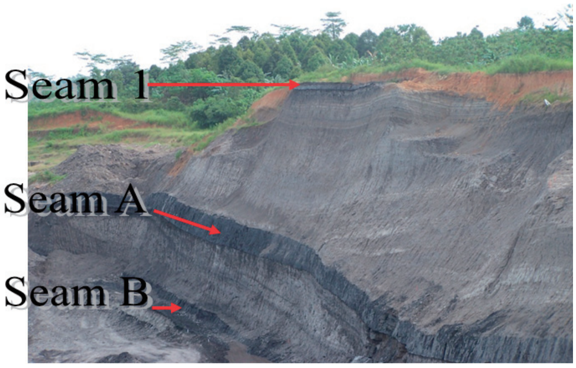


**Fig. 4** Interburden of Seam 1, A, and B from exposed highwall of open pit area.

**Table 2** Rock physical and mechanical properties[1)]

| Material | γ (gr/cm$^3$) | E (GPa) | v | C (MPa) | ϕ (…°) | B (GPa) | G (GPa) |
|---|---|---|---|---|---|---|---|
| Claystone OB 1 | 2.1 | 1.5 | 0.2 | 0.5 | 38.5 | 1.9 | 0.9 |
| Sandstone OB 1 | 2.2 | 0.5 | 0.2 | 3.7 | 21.2 | 0.5 | 0.3 |
| Claystone IB 1-A | 2.0 | 0.3 | 0.2 | 0.5 | 38.5 | 0.4 | 0.2 |
| Claystone IB A-BC | 2.2 | 0.1 | 0.2 | 0.5 | 38.5 | 0.1 | 0.1 |
| Sandstone IB A-BC | 2.2 | 0.2 | 0.2 | 7.4 | 21.6 | 0.3 | 0.1 |
| Coal | 1.3 | 0.2 | 0.3 | 2.6 | 45.6 | 0.5 | 0.1 |

E: modulus of elasticity; v: Poisson ratio; γ: density; c: cohesion; ϕ: internal friction angle; G: shear modulus; B: bulk modulus; σt: tensile strength.

**Table 3** Contact plane characteristics[1,2)]

| Contact Plane | Cohesion (MPa) | Internal Friction Angle (°) |
|---|---|---|
| Sandstone- Coal | 1.3 | 28 |
| Sandstone-Claystone | 0.1 | 28 |
| Claystone-Claystone | 0.2 | 28 |
| Sandstone-Sandstone | 1.8 | 28 |
| Coal-Coal | 1.3 | 28 |

## 3. Empirical analysis

The maximum value of surface subsidence caused by extraction of an underground longwall panel can be predicted empirically using graphical method developed by the U.K. National Coal Board. By using this method the maximum surface subsidence (S) can be predicted from surface subsidence factor (F) times the thickness of coal seam (m), where the factor is obtained from the relationship between the factor to width and depth of the opening graph.

Predicted surface subsidence (s) at various points above the longwall panel can be determined using the graph of the U.K. National Coal Board. The data used in this method consists of; h (depth of the panel center point), w (width of opening panel) and d (distance of various points along subsidence profile to the panel center point).

A correlation table between w/h and d/h is used then the values of s at various points are then calculated from the s/S ratio times S (maximum surface subsidence). Based on the dimension data of each panel the values F and w/h for each panel are obtained and presented in Table 4.

**Table 4** Values of surface subsidence factor and w/h of panel

| Panel | Surface Subsidence Factor (F) | w/h |
|---|---|---|
| AF4 | 0.65 | 0.72 |
| AF5 | 0.58 | 0.60 |
| NB F3 | 0.55 | 0.58 |
| NB F4 | 0.46 | 0.50 |

## 4. Numerical analysis

The numerical modeling is run based on 3-D Distinct Element Method using 3DEC Ver. 2.0 software. The first step is to model the geometry that is defined in three dimensions (see Fig. 5) and this is based on the GDM mine design as mentioned earlier. The model geometry is constructed by combining mine design, topographic maps, scanline data, mining situation maps, and the rock stratification. Different colors in Fig. 5 represent each rock strata found in borehole NED 02.

The model of panel geometry is referred to the panels AF4 & AF5 and panels NB F3 & NB F4 of seam A and seam BC upper respectively (Figs. 6 and 7).

After the model geometry has been defined, the second step is to model the material and discontinuities characteristics in the numerical analysis which consist of :

1. Building up discrete elements. The elements close to the panel are smaller mesh size than that of element further from the panel and that of close to the panel must have a mesh size smaller than that of panel dimension.
2. The material characteristics comply with the Mohr-Coulomb failure criterion.
3. The material properties of rock body include modulus of elasticity (E), Poisson ratio (v), density (γ), cohesion (c), internal friction angle (ϕ), shear modulus (G), bulk modulus (B) and tensile strength (σt).
4. The joint characteristics are represented by normal stiffness (Kn), shear stiffness (Ks), cohesion (C), tensile strength (σt) and internal friction angle (θ).

The third step is to determine the load and boundary conditions. The boundary conditions for the model are defined as follows; displacements in the western and eastern of the model as well as in northern and southern of the model are only permitted in the y and z directions as well as in the x and y directions. At the lower limit of the model the displacement is only permitted in the direction of x-direction and z-direction. The load applied onto the model is equivalent to the horizontal in-situ stress (σh) and is defined as 2/3 of σv for 300 m depth[3)]. The load works towards the x and z directions with g of 10 m/s$^2$.

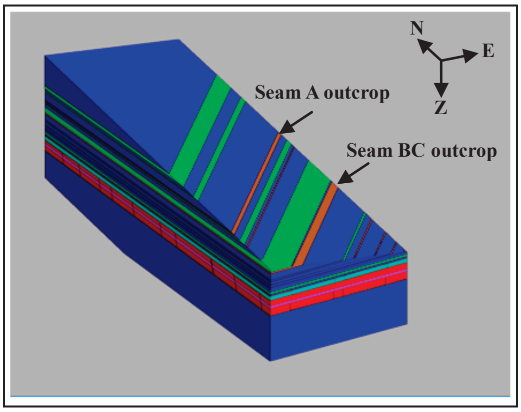


**Fig. 5** Overall geometry model for numerical analysis.

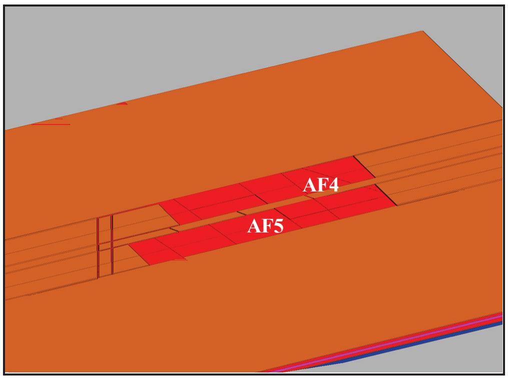


**Fig. 6** Geometry model of panel AF4 and AF5 on Seam A.

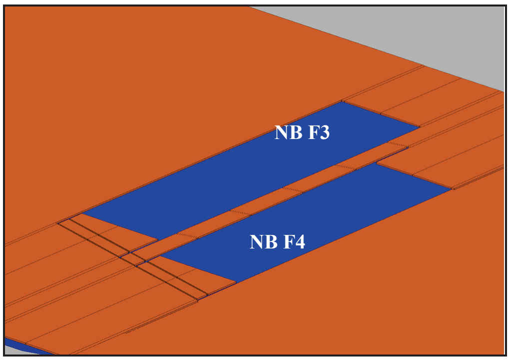


**Fig. 7** Geometry model of panel NB F3 and NB F4 on Seam BC upper.

## 5. Result and discussion

Table 5 indicates the values of the maximum surface subsidence for every single panel extraction based on calculation of the numerical and empirical methods.

The subsidence profiles associated with the data given in Table 5 is exhibited in Figs. 8 to 11. The profiles are made by taking cross section perpendicular to each panel extraction direction and through each center of the panel.

**Table 5** Maximum value of surface subsidence due to single panel extraction

| Extracted Panel | Maximum Surface Subsidence (m) | | Difference | |
|---|---|---|---|---|
| | Empirical Method | Numerical Modeling | m | % |
| A F4 | 1.8 | 1.0 | 0.8 | 44% |
| A F5 | 1.6 | 1.0 | 0.6 | 38% |
| NB F3 | 1.5 | 0.8 | 0.7 | 46% |
| NB F4 | 1.2 | 0.7 | 0.5 | 41% |

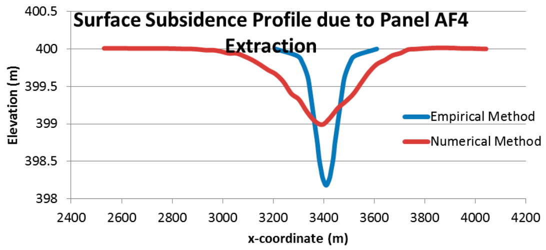


**Fig. 8** Surface subsidence profile due to panel AF4 extraction.

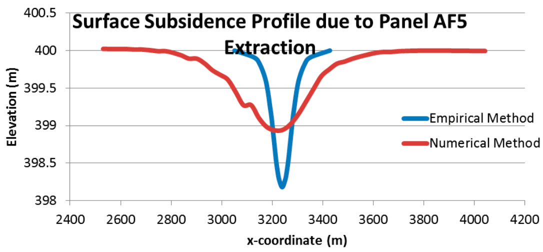


**Fig. 9** Surface subsidence profile due to panel AF5 extraction.

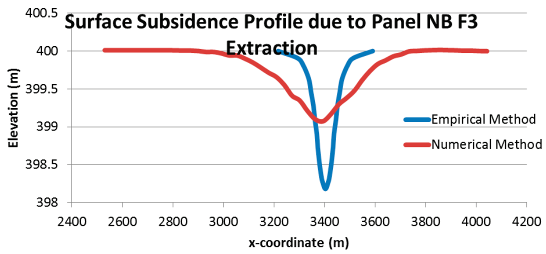


**Fig. 10** Surface subsidence profile due to panel NB F3 extraction.

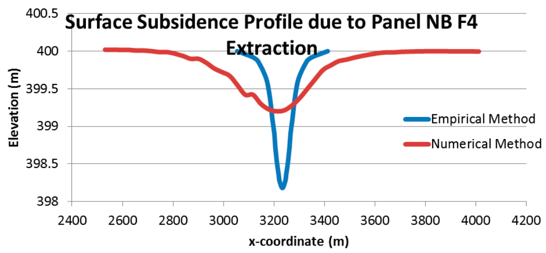


**Fig. 11** Surface subsidence profile due to panel NB F4 extraction.

The difference values of the maximum surface subsidence calculated by both methods are attributed to the following conditions: the empirical method assumes that the entire material above the coal panel being isotropic, homogeneous and continuous. In addition, the panel geometry is considered flat and the calculation is merely based on depth, width and height of a panel only. On the other hand, the numerical method obviously allows the calculation using an-isotropic, non-homogeneous, non-continuous media and complex geometry conditions. Moreover, the basic physical and mechanical properties used in the both methods remain relatively the same.

It is however important to note that the use of empirical method is always site specific as any empirical methods is derived from a certain site that possesses particular geological and geomechanical properties. Consequently, the use of any empirical method for other site might possibly yield unexpected recommendation in which cautious treatment should be exercised. Apparently, similar results are also experienced by Adamek et al. (1987) and Munson & Eichfield (1980). Thus, this research has then put special emphasis on subsidence analysis based on the numerical modeling.

Another advantage of applying the numerical method is that the subsided area can be calculated and the individual areas for each panel are given in Table 6.

**Table 6** Area of subsidence due to single panel extraction based on numerical analysis

| Extracted Panel | Area of Subsidence ($\times 10^6$ m$^2$) |
|---|---|
| AF4 | 0.6 |
| AF5 | 0.8 |
| NB F3 | 0.9 |
| NB F4 | 0.9 |

Having done the predicted subsided area for each panel, the angle of draw can also be obtained as shown in Figs. 12 to 15. It can be noted that there will be two values of the angle of draw once the seam has an inclination or is tilting[4], i.e. lower and upper angle of draws. Table 7 provides the values of panel tilt, lower angle of draw and upper angle of draw.

**Table 7** Lower limit and upper limit angle of each extracted panel

| Extracted Panel | Panel Tilt (°) | Lower limit angle (°) | Upper limit angle (°) |
|---|---|---|---|
| AF4 | 8.7 | 55 | 49 |
| AF5 | 8.7 | 54 | 50 |
| NB F3 | 8.1 | 50 | 44 |
| NB F4 | 8.1 | 49 | 44 |

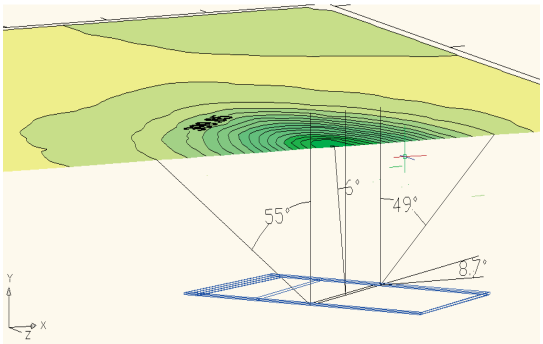


**Fig. 12** Regional influences of panel AF4.

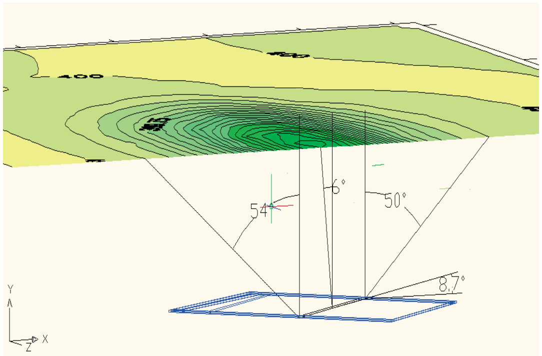


**Fig. 13** Regional influences of panel AF5.

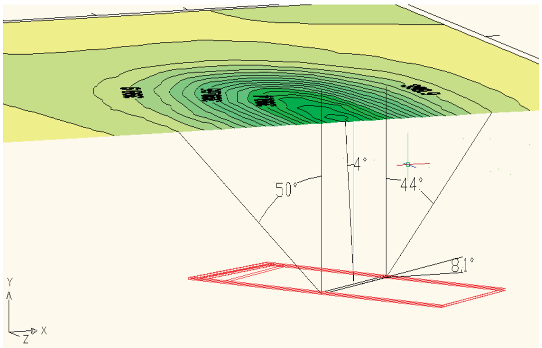


**Fig. 14** Regional influences of panel NB F3.

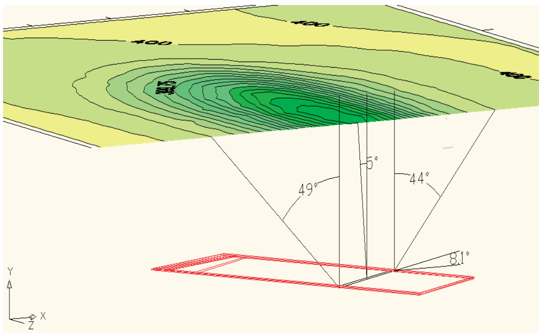


**Fig. 15** Regional influences of panel NB F4.

Numerical method suggests that panel inclination influences the center of the maximum surface subsidence[4]. Regarding this matter, Figs. 12 and 13 show evidences of inclination of 8.7° of panels AF4 and AF5 brings about 6° departure of the center the maximum surface subsidence off each panel center. Similarly happens to panels NB F3 and NB F4 which have the same panel inclination of 8.7° causes the centers of the maximum surface subsidence move away of 4° and 5° respectively (Figs. 14 and 15).

In order to determine the surface subsidence due to extraction of all panels a principle in the numerical modeling so called superposition will be applied, in which individual values of the maximum surface subsidence of each panel are added up. By applying this principle, the maximum surface subsidence due to all panel extraction is obtained i.e., 2.5 meters.

Yet, it would be interesting to find out how the values of the maximum surface subsidence calculated based on option-1: individual values of the maximum surface subsidence of each panel are added up (as mentioned above) and option-2: value of the maximum surface subsidence if entire panels are considered as one big panel extraction.

The results of the exercise of these two options are given in Table 8 and Figs. 16, 17 and 18. It can be seen that the maximum surface subsidence of the option-2 is about 88% of that option-1, but the difference of the subsided areas (option-1 = $1.76 \times 10^6$ m$^2$ and Option-2 = $1.77 \times 10^6$ m$^2$) is only about 1% and insignificant.

Having gone through all exercises it then be said that applying the superposition principle for a single panel extraction can be confirmed by that of entire panel extraction.

## 5. Conclusions

Both methods of numerical and empirical can be used to predict surface subsidence due to an underground longwall coal mining extraction.

From the foregoing analysis it can be noted that despite the fact many empirical method is usually derived from a specific site, this method suggests greater maximum surface subsidence, more practical, faster than that of the numerical one. Due to its site specific, this method is accordingly deemed inappropriate for application of this research.

The superposition principle based on single panel extraction method and entire panel extraction method can be used in generating and calculating the subsidence profile as well as maximum surface subsidence respectively. The two methods apparently provide insignificantly different results.

**Table 8** Comparison of maximum surface subsidence from numerical modeling result

| Extracted Panel | Maximum Surface Subsidence (m) | |
|---|---|---|
| | Single Panel Extraction with Superposition Principle | Entire Panel Extraction |
| AF4, AF5, NB F3, NB F4 | 2.5 | 2.2 |

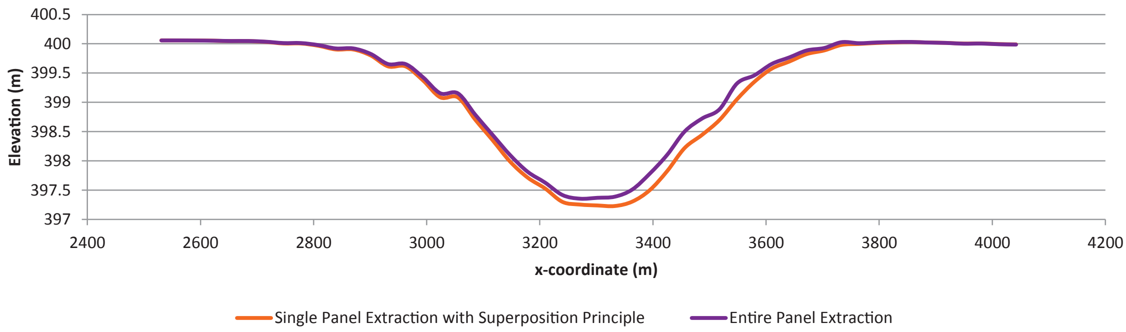


**Fig. 16** Comparison of surface subsidence profile from numerical modeling result.

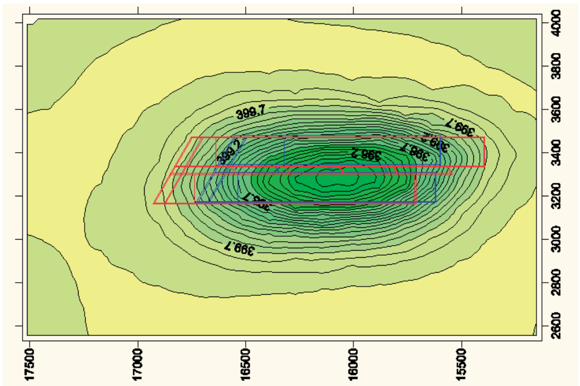


**Fig. 17** Surface subsidence area due to the entire panel extraction.

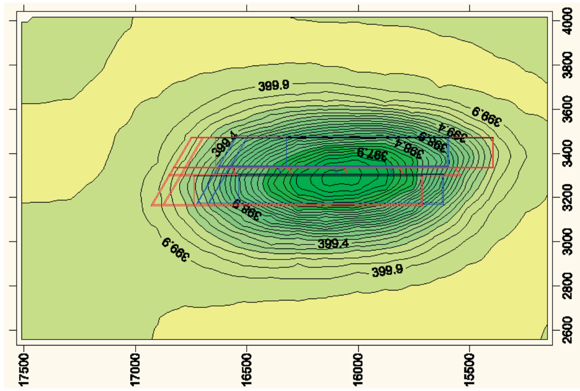


**Fig. 18** Surface subsidence area due to the single panel extraction using superposition principle.

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