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An initial assessment of the impact of coal mining on the Khe Cham washing plant (Vietnam)

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Abstract - Surface subsidence due to underground mining is a frequent problem that mine surveyors normally deal with. When some indicators like ground cracks occur, it is necessary to have a quick assessment of surface subsidence. In this case, the similar zone method proposed by D. A. Kagacovski is commonly used. By this method, the borehole data of overburden strata is used to estimate angles of movement of the subsidence trough. This article presents the result of the initial assessment of surface movement due to excavation at the Khe Cham underground mine, Quang Ninh province. With movement angles of subsidence trough estimated using stiffness coefficients of the overburden strata, it is obvious that the Khe Cham washing plant is within the dangerous deformation area due to the underground mining activities. The assessment in this study can be used to choose a reasonable solution of excavation for the safety in both underground working and surface areas.

Index Terms - Subsidence, underground mining, stiffness coefficient, similar zone method, Khe Cham washing plant

1 INTRODUCTION

1.1. Subsidence due to underground mining

The mining industry is one of the main sectors contributing to the economy of Vietnam with a rapid increase in production year by year (N. Q. Long, 2016). The main coal basin of Vietnam is in Quang Ninh province. While underground mining has been increasingly common in Quang Ninh, this technology also causes several environmental problems to the region (N. Q. Long et al., 2017). One of the major problems is surface movement and deformation (R. P. Singh & Yadav, 1995). There have been many serious incidents induced by this issue recorded in the Quang Ninh coal field (N. Q. Long, 2016; N. Q. Long et al., 2017). Therefore, surface movement and deformation due to underground mining has gained serious attention from scientists and mining managers.

A subsidence trough will be formed after a working coal face has been exploited. Many methods have been developed and continuously improved to better predict and estimate land subsidence due to mining activities (Jarosz, A. at al, 1990). Several methods and theories were applied for Subsidence Assessment caused by underground mining (M. Buczek, 2018). The range and value of the subsidence are related to factors such as mining depth, coal seam thickness, dip angle, size of working face, overlying strata characteristics, etc. (Fan et al., 2015; Sasaoka et al., 2015). There are two main axes of the subsidence trough with one in the strike direction and another in the dip direction. The strike direction is also the mining direction in order to exploit and extract coal easily (Kratzsch, 1983).

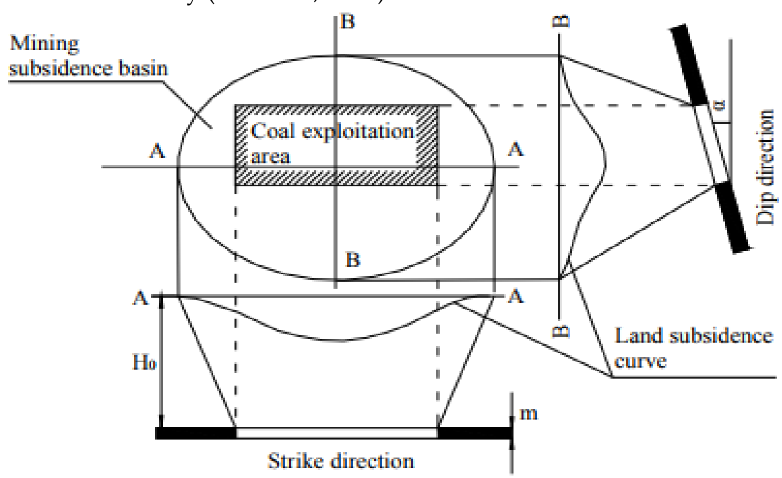

Fig 1. Profile of the mining subsidence basin in the strike and dip directions (Fan, Gao, Yang, Deng, & Yu, 2015; Peng, 1984)

According to Fan et al. (2015), in the strike direction, the surface will begin to subside when the coal has been exploited over a certain distance, generally $0.25H_0$–$0.5H_0$ (Fig 2). Figure 2 assumes that the coal seam is horizontal and that W1–W4 is the dynamic subsidence curves. W1-W4 curves present the development of the subsidence trough. The trough becomes deeper along the strike direction as the exploitation area increases in size. When the mining plane arrives at point 1, subsidence curve W1 is formed.

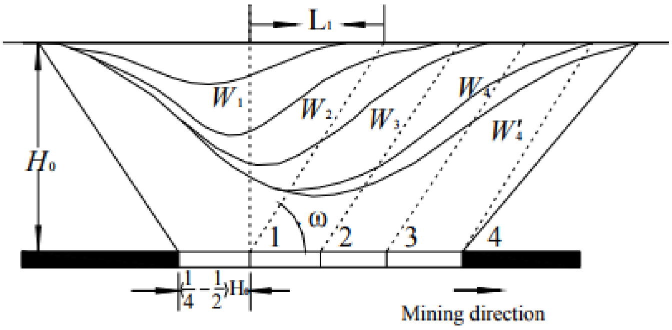

Fig 2. Formation of a mining subsidence basin (Fan et al., 2015; Zou & Deng, 2003)

As the coal continues to be exploited, the curve expands to be W2, resulting in a greater area of subsidence. When mining of the working face is complete, curve W4 is formed. The process from W1 to W4 is that of dynamic deformation. The subsidence then gradually becomes residual deformation, and W'4 represents the final mining subsidence basin in which almost no land movement occurs. The advance distance of influence (L1) and the advance angle of influence (ω) can be used to predict the range of mining subsidence so that action can be taken to prevent buildings from being damaged or other measures taken to control potential disasters.

To monitor the subsidence related to mining, observation stations are arranged along the strike and inclination (dip) directions above the working coal face. Several methods have been used to determine the subsidence of these observation points, including leveling, global positioning system (GPS), and total station measurements. However, it normally takes a long time for setting observation stations whereas it is necessary to have an initial assessment of surface subsidence, and boreholes' data are crucial for this activity.

1.2. Khe Cham washing plant

The construction of the Khe Cham washing plant is in the 2020-2030 planning of coal mine development that was approved by the Prime Minister of Vietnam in 2015 (Governmental Decision 403/QĐ – TTg). The plant has been building by the Vietnam national coal mineral industries holding corporation limited (Vinacomin) (Decision 106/QĐ-TKV of Vinacomin).

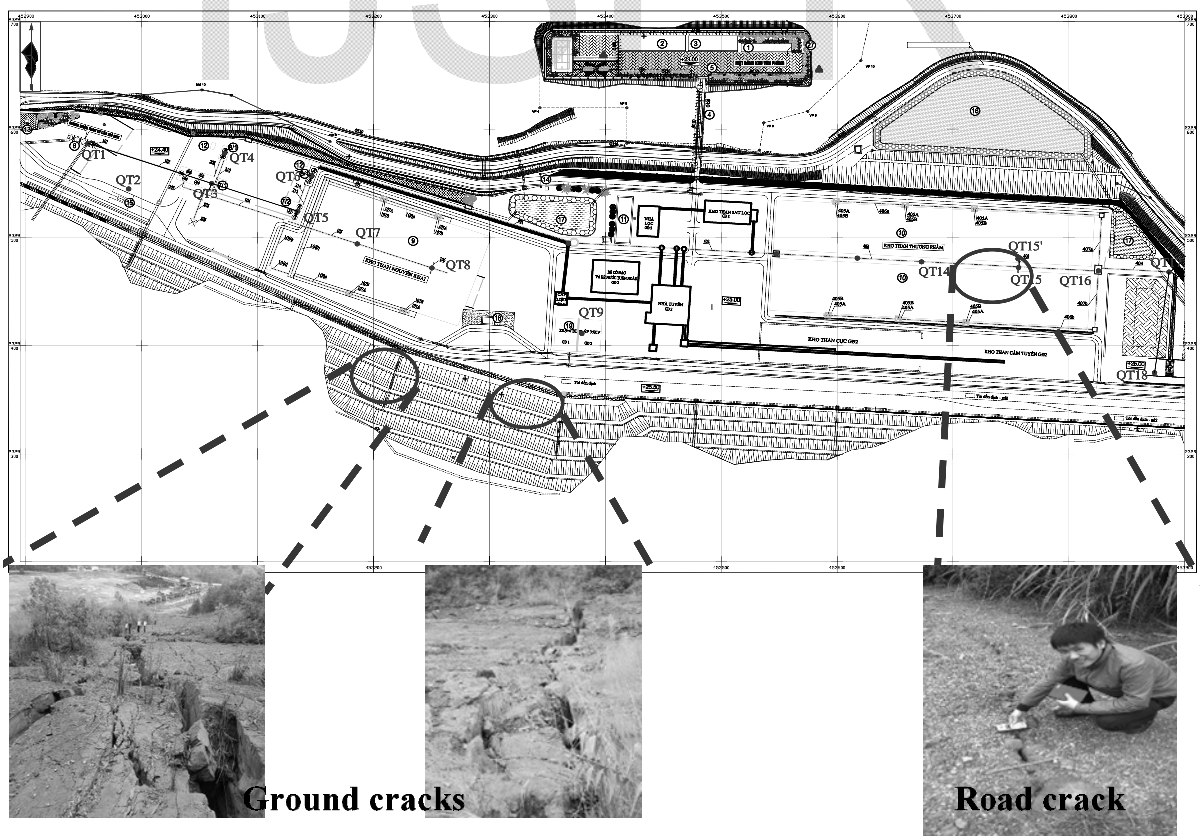

Fig 3. Khe Cham washing plant and the photographs of ground cracks and road cracks due to mining activities. The photos were taken on 24-02-2016

The Khe Cham plant is in the Mong Duong ward, Cam Pha city, Quang Ninh province. Its boundary is marked by the following points in Table 1:

Table 1. The coordinates of the Khe Cham washing plant's boundary

Point	Coordinates	
	X	Y
A	2329200	452800
B	2329700	452800
C	2329700	454400
D	2329200	454400

The altitude of the land surface where the plant located is an average of +63 m. The surrounding area is with waste rock, tailings, and planting acacia forests. Recently, subsidence has occurred in the area (Fig 3), and importance is placed on the determination of causes and solutions to ensure the safe operation of the plant. Unfortunately, there has been no study of subsidence for this area up to now. This study is to evaluate the subsidence of the area of the building plant with a focus on the determination of the edge of subsidence trough based on the geological data.

1.3. Underground mining technology in the Khe Cham coal mine

There are 12 coal seams in Khe Cham including seams V.16a, V.16, V.15, V.15, V15a, V.14-5. V14-4, V14-2, V14-1, V13-2, V13-1a, V13-1, V12, and V11 (Nguyen, 2017). The exploitation of the open part of seams 11, 12, 13, 14, 15, and 16 was finished by using surface mining technology in 2006. Since then, all remaining seams have been exploited by underground mining technology. The Khe Cham coal mine has employed mining without permanent pillars. Recently, there have been two working faces such as faces No 13.1-8V and 12.7 at levels -225 and -100, respectively (Nguyen, 2017). It is noted that these faces might be the major contribution to the subsidence of the Khe Cham plant.

Table 2. Features of face 13.1-8V and 12.7

No	Designation	Value (m)
1	Working level	-225 ÷ -100
2	Length of face in the dip direction	110 ÷ 105
3	Length of face in the strike direction	90 ÷ 236
4	Average depth of working face	254 ÷ 222

2. METHODOLOGY

2.1. Similar zone (Kagacovski method)

As there have not been any studies on the surface movement and deformation due to underground mining in the study area, the method used to identify the angle of draw was the similar zone method (VNIMI, 1998). The method was proposed by prof D. A. Kagacovski. In this method, the stiffness coefficient (SC) of overburden strata is determined based on the data of boreholes constructed in the subsided area. This coefficient will be used to identify the group of the study area in the mining category. In the next stage, the angle of draw will be chosen based on the group.

2.2. Determination of the stiffness coefficient

According to K. B. Singh and Singh (1998), the angle of draw is influenced by the strength and composition of superincumbent strata. They noted that the strong massive overburden was associated with high value of angle of draw, and weak and soft overburden was more likely to result in a small angle of draw. It is noted that the strength of overburden is measured by the stiffness coefficient, and this coefficient is determined by following steps:

- Compute the SC of overburden rocks consisting of sandstone and fine-grained sandstone by following equation:

$$f_c = \frac{\sum m_{c_i} f_{c_i}}{\sum m_{c_i}} 10^{-2} \quad (1)$$

- Compute the SC of overburden rocks consisting of siltstone and claystone by the following equation:

$$f_m = \frac{\sum m_{m_i} f_{m_i}}{\sum m_{m_i}} 10^{-2} \quad (2)$$

- Compute the SC of coal seams by the following equation:

$$f = \frac{30 f_c + 70 f_m}{100} \tag{3}$$

- The ratio of the SC of weak overburden strata to that of strong overburden strata:

$$A = \frac{f_m}{f_C} \tag{4}$$

- Other indices:

$$C\% = \frac{\sum Mc}{\sum Mc + \sum Mm} \tag{5}$$

$$D\% = \frac{\sum Mm}{\sum Mc + \sum Mm} \tag{6}$$

where, Mc and Mm are the average thickness of stiff and soft overburden stratums, respectively.

In order to determine the influenced extent of underground coal mining activities, three profiles across the area of the Khe Cham washing plant, one in the strike direction and two in the dip direction were used. The maximum value of subsidence is calculated by following equations:

$$\eta_{max} = q_0.m_{HQ}.\cos\alpha.N_1.N_2 \tag{7}$$

$$B = \frac{1}{a_o}[tag\alpha - \frac{(h + H_M)}{H_{CP}}] \geq 0 \tag{8}$$

$$N_1 = \frac{D_1}{H} \tag{9}$$

$$N_2 = \frac{D_2}{H} \tag{10}$$

where, D1 and D2 are the length of faces in the dip and strike directions, respectively. H is the average depth of faces. It is noted that N1 and N2 depend on the stiffness coefficient and the category of mine.

In this study, the subsidence trough was divided into ten parts in which the value of subsidence, tilt, curvature, horizontal movement and deformation were computed. Also, the distribution function of above components is expressed as:

$$S(z) = \frac{\eta_i}{\eta_m}; \tag{11}$$

$$S'(z) = \frac{i_i}{\frac{\eta_m}{L}}; \tag{12}$$

$$S''(z) = \frac{K_i}{\frac{\eta_m}{L^2}}; \tag{13}$$

$$F(z) = \frac{\xi_i}{0,5a_0\eta_m} \tag{14}$$

$$F'(z) = \frac{\varepsilon_i}{\frac{0,5a_0\eta_m}{L}} \tag{15}$$

3. RESULTS AND DISCUSSION

3.1. Geological condition of the Khe Cham coal mine

The overburden strata consist of sediments from the Triassic period, and the Quaternary period with details shown in Table 3.

Table 3. Stratigraphy of the Khe Cham coal mine

Age	Formation	Lithology
Triassic	Hon Gai - T3n-r hg1	Devoid of any coal seams; conglomerate, breccia, sandstone, little silt-stone, claystone, and clay-coal stones.
	Hon Gai - T3n-r hg2	Continent sediments and gulf sediments with coal seams Conglomerate, breccia, sandstone, little siltstone, claystone, and clay-coal stones.
	Hon Gai - T3n-r hg3	Devoid of any coal seams; Conglomerate, breccia, sandstone, little silt-stone, claystone, and clay-coal stones.
Quaternary		Loose conglomerate, breccia, sandstone, little siltstone, and claystone.

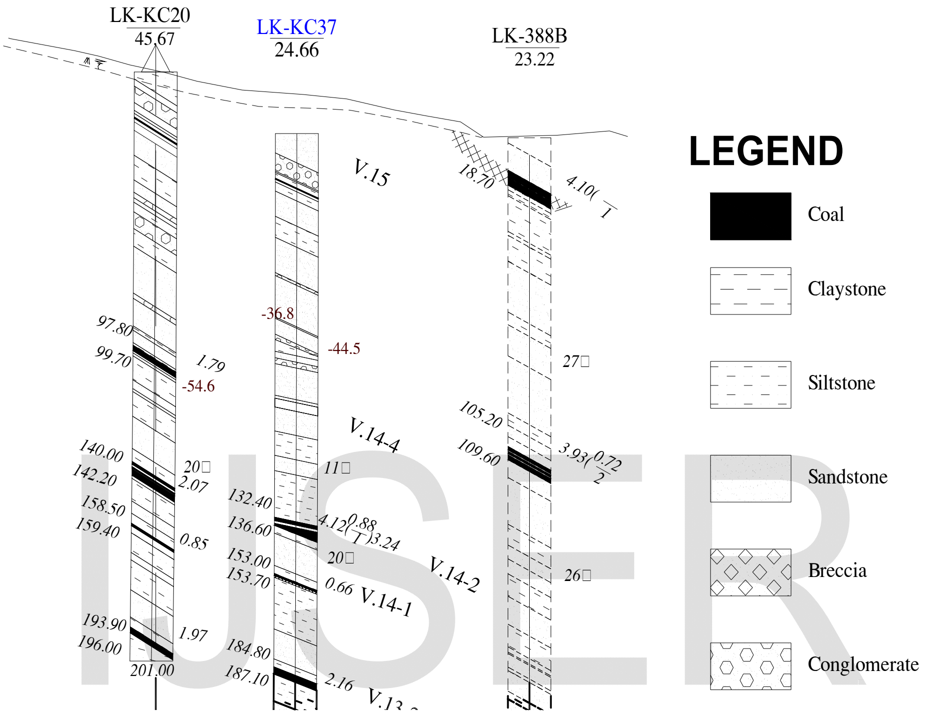

Fig 4. Strata of the Khe Cham coal mine

The thickness varies between layers, 5÷10 m for conglomerate and breccia, 10÷15 m for sandstone, 10÷20 m for siltstone, and thin layers of claystone just above the roof or under the floor of seams.

Table 4. Overview of the Khe Cham coal mine

No	Features of face 13.1-8V, 12.7	Unit	Seam 12 and 13
1	Working level	m	-225 ÷ -100
2	Thickness of coal seam	m	1.9 ÷ 2,1
3	Dip of the coal seam	degree	10 ÷ 22
4	Thickness of overburden strata	m	5

There are four lines of geological exploration in the area where the Khe Cham plant located, namely III, IIIb, XIII, and XIIIb. Several boreholes were constructed along these lines (Fig 4). The analyzing result of these boreholes' data was to determine the stiffness coefficients which are shown in Table 5.

Table 5. Overburden strata stiffness coefficients of the Khe Cham coal mine

Lines	Boreholes	f	A	C%	D%
T IIIB	2554	4.4	0,4	72	28
T III	393	5.1	0.4	80	20
TXIIIB	2730	5.09	0.4	40	60
TXIII	2628	5.51	0.5	40	60
Average value		4.8			

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3.2. Determination of movement angles of the subsidence trough

Based on the value of the stiffness coefficient calculated for the Khe Cham (f = 4.8), this mine was placed into the group VI. According to VNIMI (1998), all mines belong to the group VI will have movement angles shown in Table 6.

Table 6. The angle of draw of subsidence trough at the Khe Cham coal mine

No	Designation	Symbol	Unit	Value
1	Limit angle	$\delta 0$	degree	65
		$\gamma 0$	degree	65
		$\beta 0$	degree	55
2	Displacement angle	δ	degree	75
		γ	degree	75
		β	degree	60
3	Crack angle	δ''	degree	80
		γ''	degree	80
		β''	degree	70
4	Complete movement angle	$\psi 1$	degree	60
		$\psi 2$	degree	60
		$\psi 3$	degree	57
5	Maximum subsidence angle	θ	degree	81
6	Displacement overburden angle	φ	degree	45
7	Vertical displacement value	q0		0.7
8	horizontal displacement value	a0		0.3
9	Period of dangerous movement	t	year	9

Table 7. Value of maximum subsidence

No	Symbol	Faces	
		12.7	**Face 13.1-V8**
1	q_0	0.7	0.7
2	B	2.38	2.01
3	m(m)	1.9	2.1
4	H(m)	254	222
5	D_1(m)	110	105
6	D_2(m)	90	236
7	α (degree)	10	22
8	D_1/H	0.43	0.47
9	D_2/H	0.35	1.06
10	N_1	0.4	0.4
11	N_2	1.0	1.0
12	η_{max}	766	415

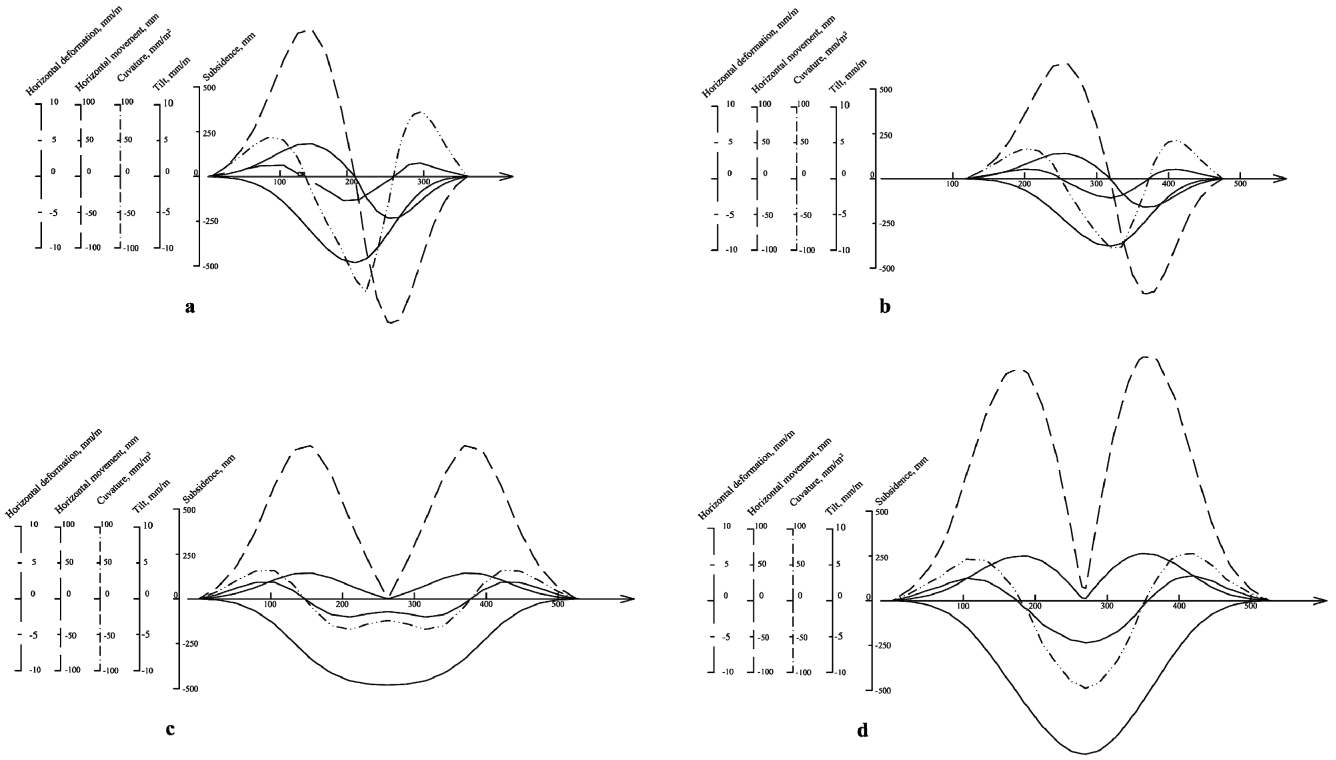

Fig 5. The component of ground movement and deformation due to (a) face 13.1- 8V (profile 2-2); (b) face 12.7 (profile 2-2); (c) 13.1- 8V (profile 6-6); (d) faces 13.1- 8V and 12.7 (profile 6-6)

The construction of subsidence profiles with faces and angles of the draw is shown in Fig 6. It can be seen from these figures that the Khe Cham washing plant is totally within the dangerous deformation area due to the operation of faces 12.7 and 13.1-V8.

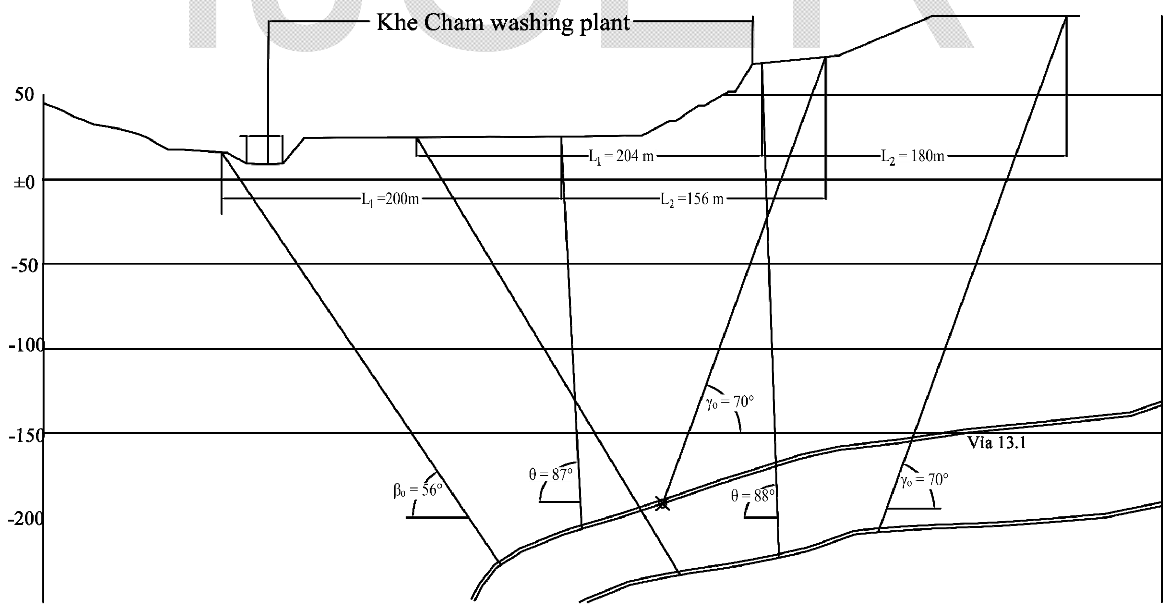

Fig 6. Subsidence trough profile

4. CONCLUSION

The main objective of this study is to assess the influence of underground mining activities on the area of the building Khe Cham washing plant. The ground displacement and deformation due to the underground mining were defined by the angle of the draw which was determined by using the similar zone method. This method is appropriate for initial assessment of surface movement and deformation. Based on the data of boreholes constructed in the study area, the stiffness coefficient (f) was computed. The value of this coefficient (f=4.8) indicates that the overburden strata are strong, and the Khe Cham mine is placed into group VI. With the angle of draw suggested in group VI, the subsidence profile was constructed. From the constructed subsidence profile, the Khe Cham washing plant is totally within the dangerous deformation area due to the operation of faces 12.7 and 13.1-V8.

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