# SURFACE SUBSIDENCE MONITORING USING GPS TECHNOLOGY - RTK METHOD – AT LIVEZENI MINE

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**Abstract**

The Livezeni Mine is situated in eastern part of the Jiu Valley coal basin. The phenomenon of displacement and deformation of the surface land, continues to present a wide interest in the implications of environmental problems and protection of existing construction area. The researches in this direction have led to the conclusion that the observations made in the areas affected by underground mining can be done short-term forecasts, medium and long forecasts about the phenomenon analyzed. These forecasts have been particularly important in the sense that future studies can be made for sustainable development of areas affected by underground mining. Throughout the duration of the existence of a mining the topography is an important component. Topogeodetic methods to study modern methods of tracking the movement of the land surface in the mining areas is a prerequisite for evidence the phenomenon in the future. The paper presents the method applied to monitor the surface subsidence at the Livezeni Mine.

## 1. Perimeter description of Livezeni Mine

The Livezeni Mine is situated in the eastern part of the Jiu Valley coal basin limited by the Petrila and Petrila Sud Mine's at north, Sălătruc Mine at south, Dâlja and Iscroni at west and Lonea Mine at east (fig. 1) [1].


**Fig. 1.** *Jiu Valley Coal Basin*

## 2. Surface subsidence monitoring in the case of Livezeni Mine using the RTK method

For surface subsidence monitoring using GPS technology – RTK method – on the general plan of the mine (figure 2), on which is flagged mined areas (longwall panels), have been designed the alignments after which we want to make measurements [7], [8].

So, four alignments have been designed, namely [8]:

- an transversal alignment $T_1 – T_1$ consisting of 24 benchmarks, the distance between them is approximately 50m;
- three longitudinal alignments $L_{(3-4)} – L_{(3-4)}$, $L_5 – L_5$ and $L_6 – L_6$ located in the center of each panel. Those are composed of 20 benchmarks, the distance between them is also approximately 50m.

The coordinates of those benchmarks have been measured on the map and introduced in the GPS's memory (on the memory card).

Using the stakeout program (**09 Stakeout)** at the main measurement (the first measurement), which has been made at 15.09.2010, were stakeout all the points that forms the alignments, measuring at the same time their heights [6].

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The representation of land surface according to the distance between benchmarks, for each alignment in part, is graphically presented in figures 3, 4, 5 and 6.

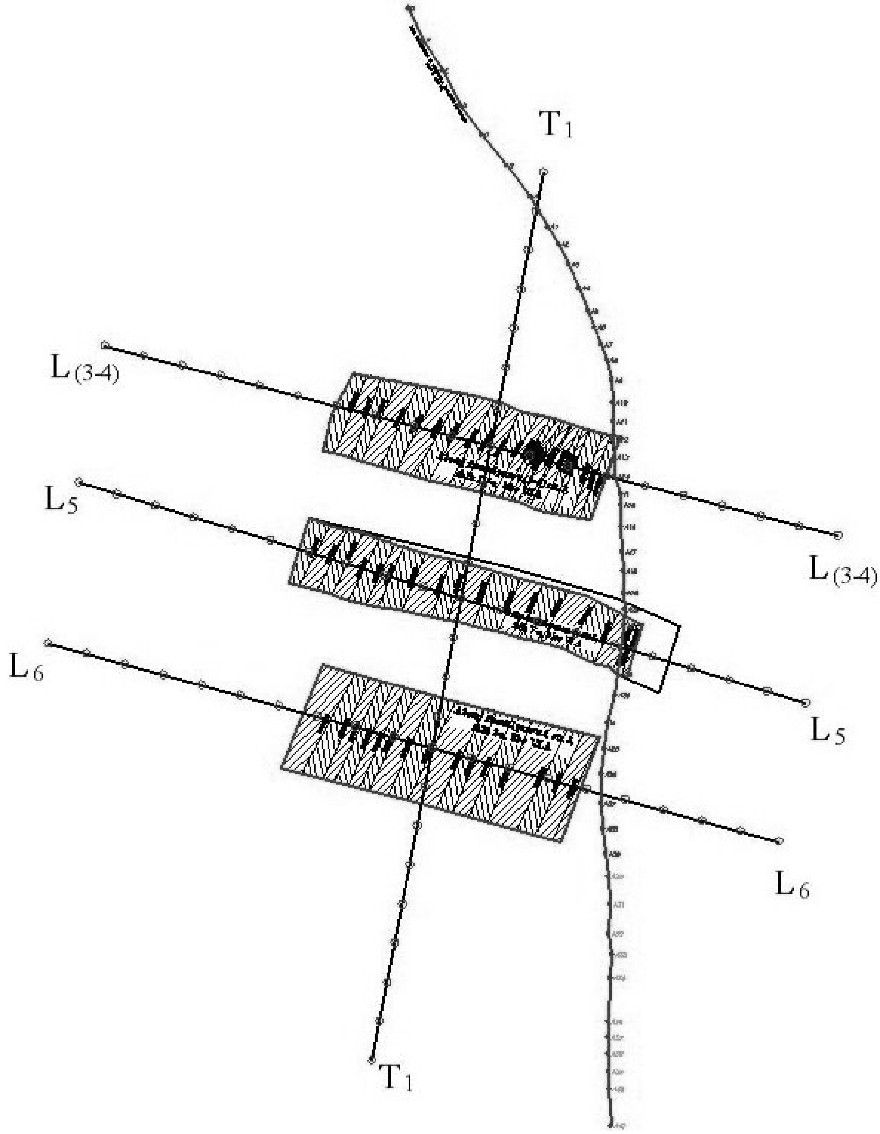


**Fig. 2** *Designed alignments for subsidence monitoring*

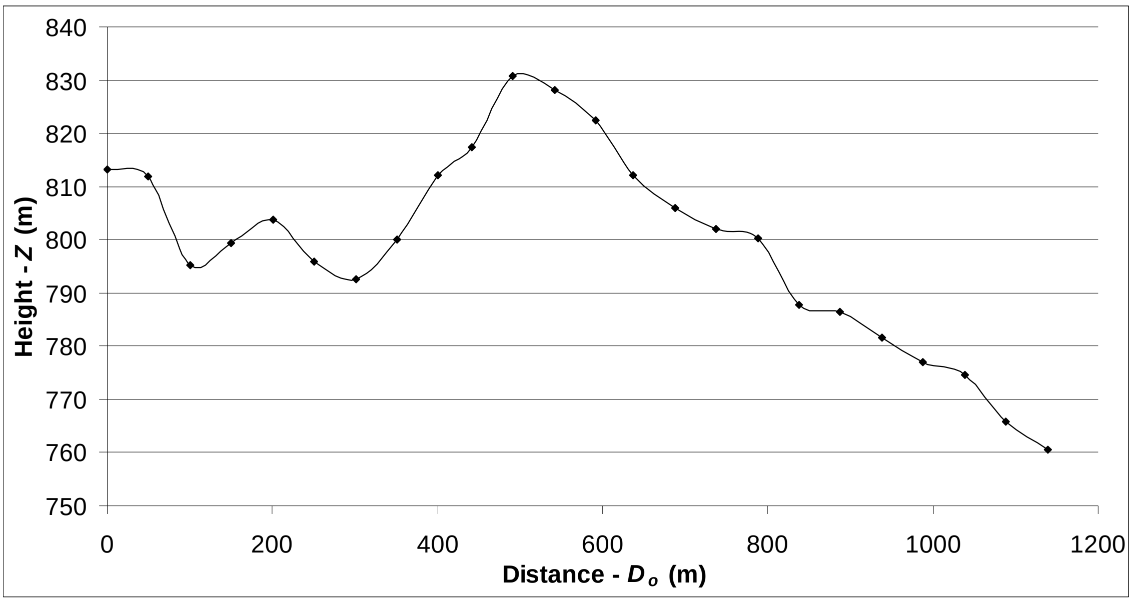


**Fig. 3** *Surface configuration in the transversal profile $T_1 – T_1$*

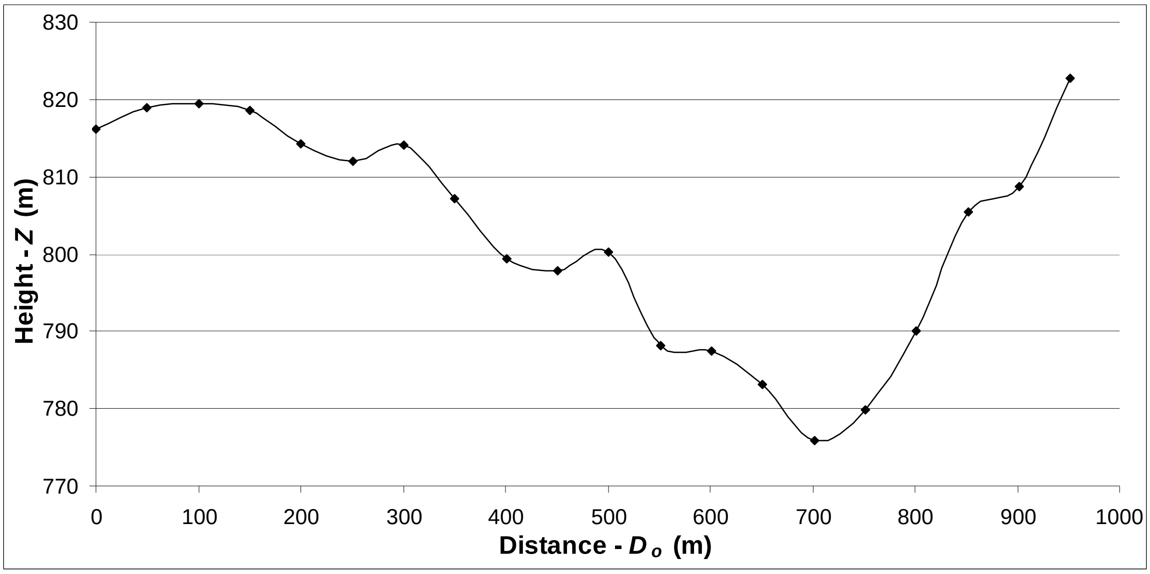


**Fig. 4** *Surface configuration in the longitudinal profile $L_{(3-4)} - L_{(3-4)}$*

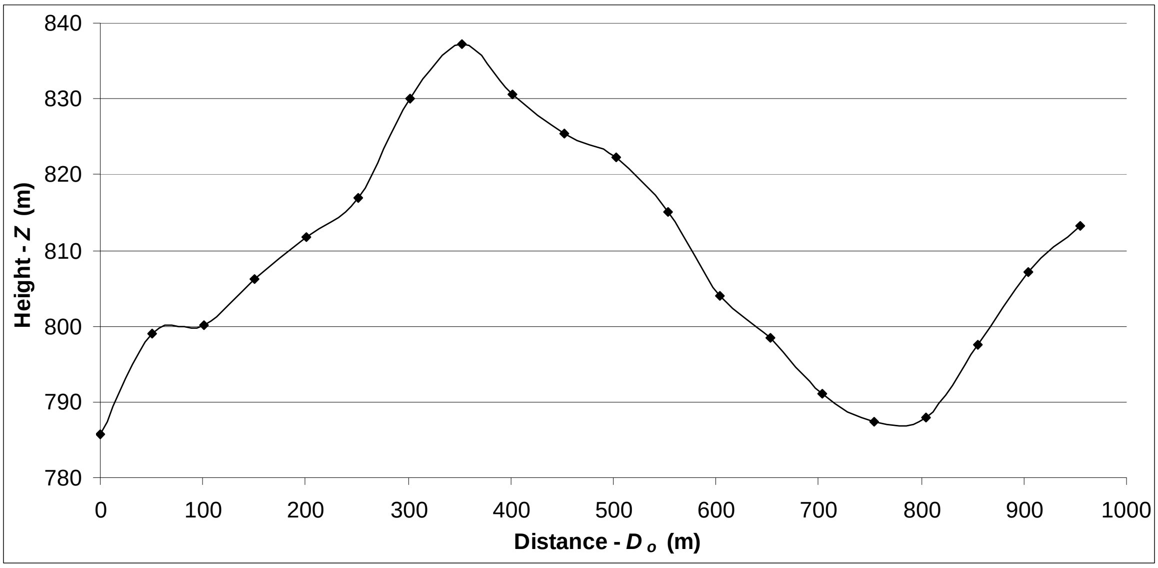


**Fig. 5** *Surface configuration in the longitudinal profile $L_5 - L_5$*

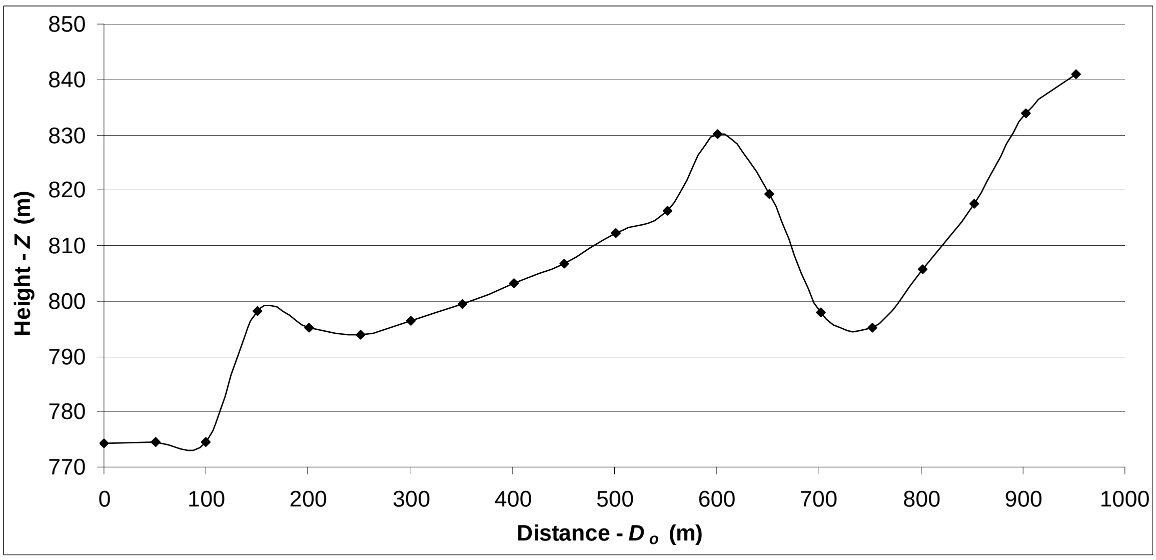


**Fig. 6** *Surface configuration in the longitudinal profile $L_6 - L_6$*

In order to measure the surface movement, the second measurement was made after 6 months, on 19.03.2011 [8].

Using relation 1 the surface subsidence have been determined for each benchmark.

$$S_i = H_i^* - H_i \quad [mm] \tag{1}$$

In table 1 are presented the cumulated distance between benchmarks and their subsidence.

**Table 1.** *Measured subsidence*

| Transversal alignment $T_1 - T_1$ | | |
|---|---|---|
| **Benchmark** | ***D*** (m) | ***S*** (mm) |
| **1** | 0,000 | 6 |
| **2** | 50,086 | 21 |
| **3** | 100,218 | 86 |
| **4** | 150,392 | 142 |
| **5** | 200,504 | 168 |
| **6** | 250,639 | 206 |
| **7** | 300,771 | 242 |
| **8** | 350,923 | 296 |
| **9** | 401,079 | 319 |
| **10** | 441,134 | 317 |
| **11** | 491,415 | 315 |
| **12** | 541,681 | 313 |
| **13** | 591,979 | 309 |
| **14** | 637,436 | 301 |
| **15** | 687,564 | 299 |
| **16** | 737,644 | 278 |
| **17** | 787,738 | 266 |
| **18** | 837,849 | 248 |
| **19** | 887,931 | 216 |
| **20** | 938,027 | 197 |
| **21** | 988,132 | 151 |
| **22** | 1038,259 | 102 |
| **23** | 1088,331 | 74 |
| **24** | 1138,429 | 14 |

| Longitudinal alignment $L_{(3-4)}$ - $L_{(3-4)}$ | | |
|---|---|---|
| **Benchmark** | ***D*** (m) | ***S*** (mm) |
| **25** | 0,000 | 17 |
| **26** | 50,104 | 45 |
| **27** | 100,207 | 92 |
| **28** | 150,318 | 132 |
| **29** | 200,429 | 153 |
| **30** | 250,503 | 187 |
| **31** | 300,993 | 199 |
| **32** | 350,707 | 234 |
| **33** | 400,824 | 248 |
| **34** | 450,914 | 257 |
| **17** | 501,060 | 266 |
| **35** | 551,144 | 251 |
| **36** | 601,256 | 222 |
| **37** | 651,349 | 189 |
| **38** | 701,454 | 165 |
| **39** | 751,545 | 125 |
| **40** | 801,671 | 89 |
| **41** | 851,749 | 62 |
| **42** | 901,875 | 35 |
| **43** | 951,975 | 9 |

| Longitudinal alignment $L_5$ - $L_5$ | | |
|---|---|---|
| **Benchmark** | ***D*** (m) | ***S*** (mm) |
| **44** | 0,000 | 21 |
| **45** | 50,279 | 52 |
| **46** | 100,535 | 84 |
| **47** | 150,813 | 145 |
| **48** | 201,096 | 189 |
| **49** | 251,346 | 205 |
| **50** | 301,618 | 243 |
| **51** | 351,890 | 274 |
| **52** | 402,173 | 285 |
| **53** | 452,466 | 299 |
| **13** | 502,709 | 309 |
| **54** | 552,992 | 286 |
| **55** | 603,265 | 267 |
| **56** | 653,539 | 210 |
| **57** | 703,799 | 178 |
| **58** | 754,072 | 154 |
| **59** | 804,358 | 121 |
| **60** | 854,640 | 103 |
| **61** | 904,921 | 68 |
| **62** | 955,189 | 16 |

| Longitudinal alignment $L_6$ - $L_6$ | | |
|---|---|---|
| **Benchmark** | ***D*** (m) | ***S*** (mm) |
| **63** | 0,000 | 9 |
| **64** | 50,161 | 17 |
| **65** | 100,253 | 37 |
| **66** | 150,432 | 55 |
| **67** | 200,553 | 89 |
| **68** | 250,704 | 153 |
| **69** | 300,837 | 196 |
| **70** | 350,996 | 231 |
| **71** | 401,123 | 266 |
| **72** | 451,238 | 302 |
| **9** | 501,374 | 325 |
| **73** | 551,539 | 319 |
| **74** | 601,672 | 297 |
| **75** | 651,845 | 245 |
| **76** | 701,949 | 201 |
| **77** | 752,058 | 168 |
| **78** | 802,187 | 123 |
| **79** | 852,356 | 93 |
| **80** | 902,492 | 45 |
| **81** | 952,603 | 17 |

In figures 7 – 10 is represented the measured subsidence occurred to surface due to underground mining.

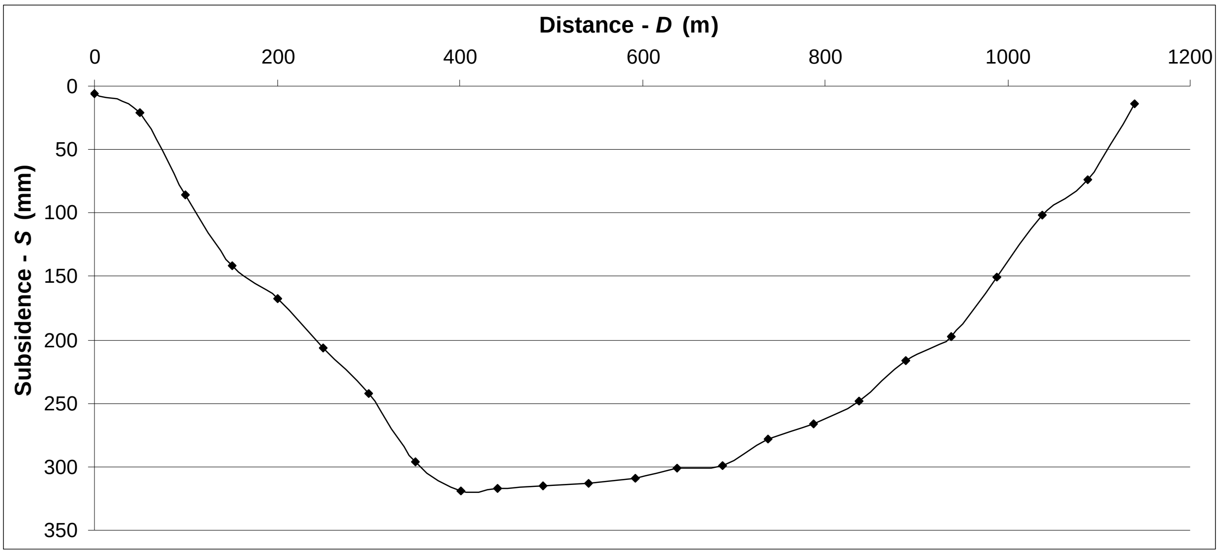


**Fig. 7**. *Surface subsidence measured in the transversal profile $T_1 – T_1$*

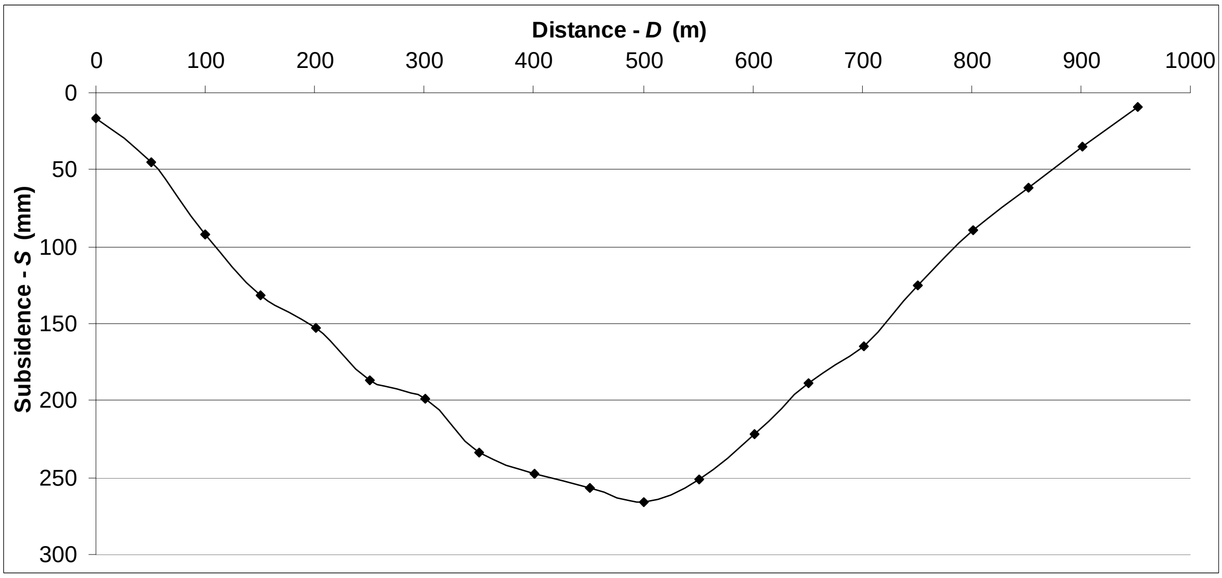


**Fig. 8** *Surface subsidence measured in the longitudinal profile $L_{(3-4)} – L_{(3-4)}$*

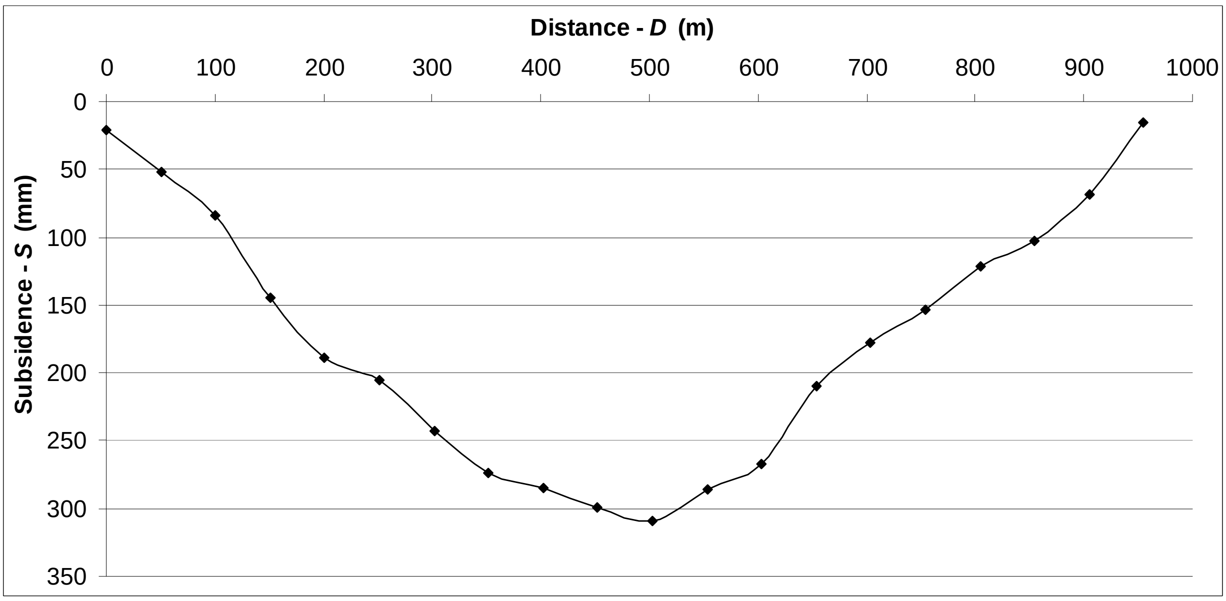


**Fig. 9** *Surface subsidence measured in the longitudinal profile $L_5 – L_5$*

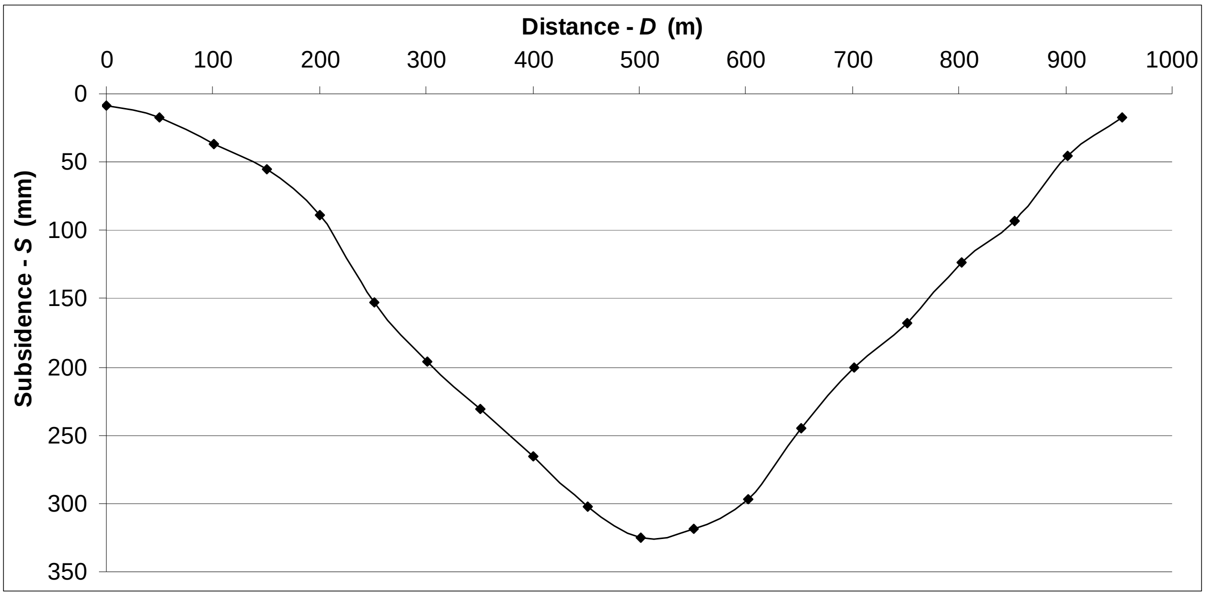


**Fig. 10** *Surface subsidence measured in the longitudinal profile $L_6 - L_6$*

The statistical approximation of the measured subsidence, using the profile functions, will be shown bellow.

**3. The statistical approximation of the measured subsidence at the Livezeni Mine**

In 1981, Peng and Chen developed the following negative exponential function of the subsidence profile on the major cross section of the subsidence basin [2], [3], [4], [5]:

$$S(x) = S_{\max} \cdot A \tag{2}$$

where $A = e^{-a \cdot z^b}$; $S_{max}$ is the maximum subsidence; $a$, $b$ are constants; $z = \frac{x}{s}$; $x$ is the horizontal distance from the origin (which is located at the center of the subsidence profile); $s$ is the half width of the subsidence basin [2], [3].

In order to obtain the complete subsidence profile, the relation (2) must be applied twice, for the left and right side of the subsidence profile, resulting different coefficients for each half of the subsidence profile: $a_s$, $b_s$ and $a_d$, $b_d$.

Applying the relation of Peng and Chen in this way for the measured subsidence in the case of Livezeni Mine results [8]:

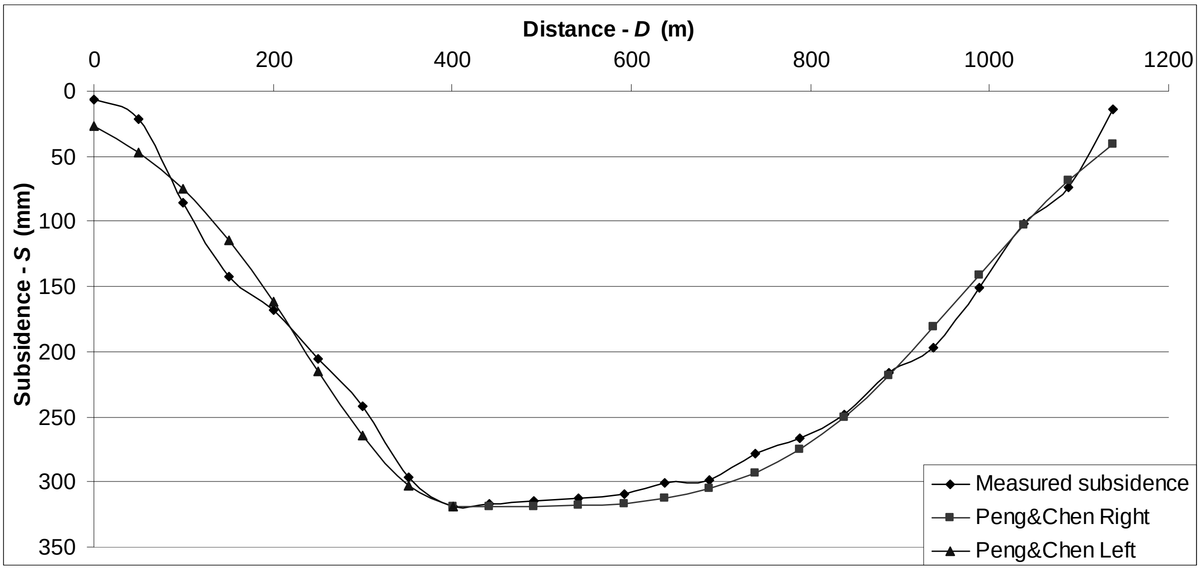


**Fig. 11** *Statistical approximation of the measured subsidence for the transversal profile $T_1 - T_1$*

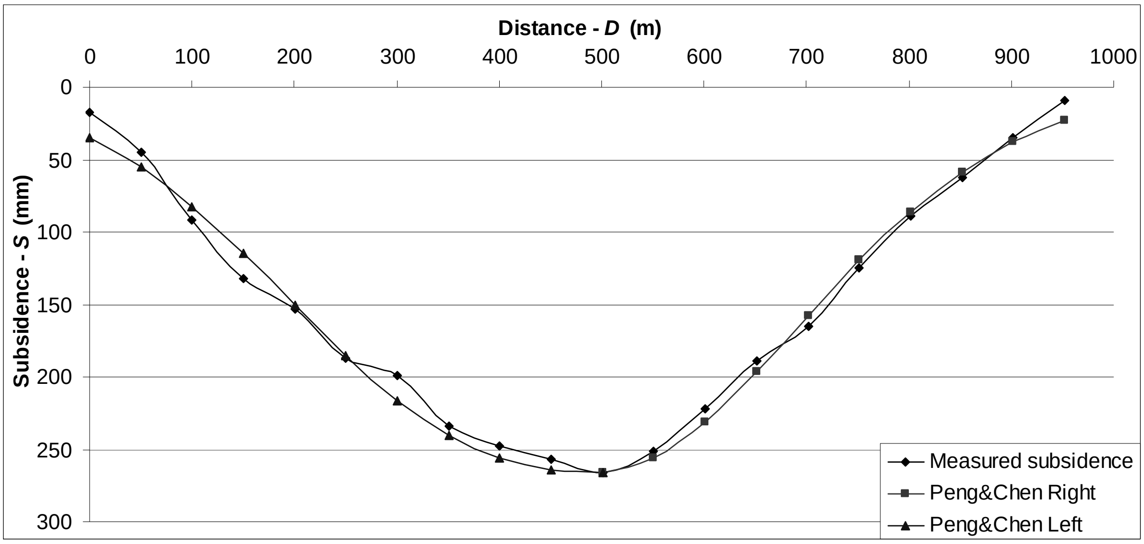


**Fig.12** *Statistical approximation of the measured subsidence for the longitudinal profile* $L_{(3\text{-}4)}$–$L_{(3\text{-}4)}$

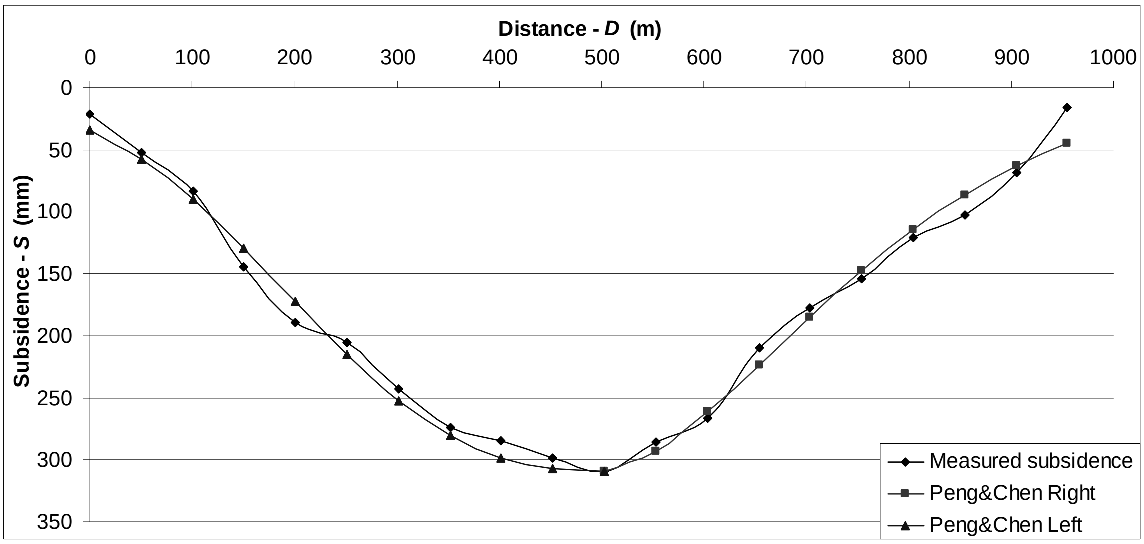


**Fig. 13** *Statistical approximation of the measured subsidence for the longitudinal profile* $L_{(5)}$–$L_{(5)}$

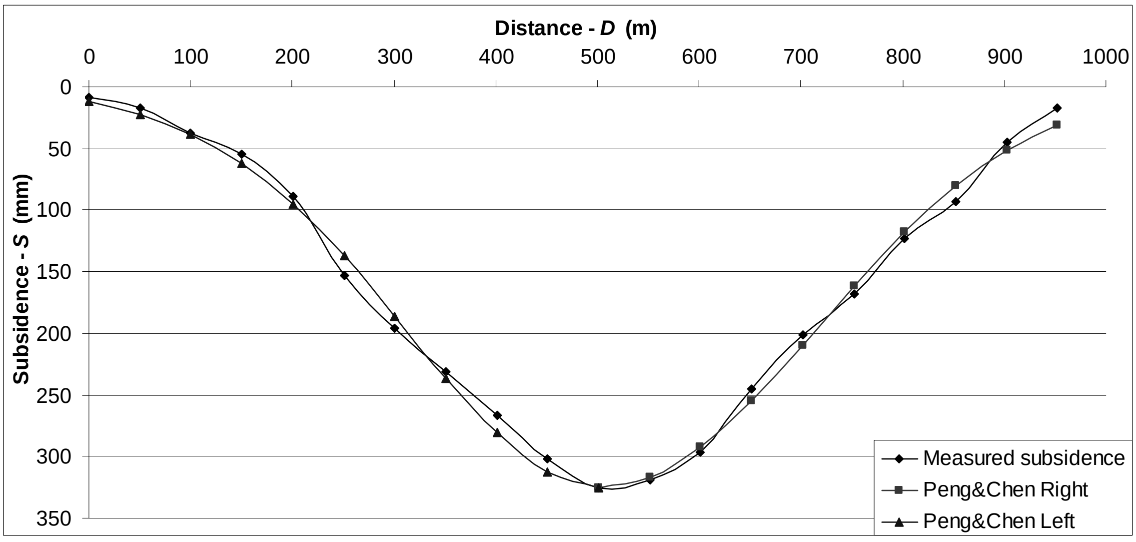


**Fig. 14** *Statistical approximation of the measured subsidence for the longitudinal profile* $L_{(6)}$–$L_{(6)}$

As cam be seen, the profile function developed by Peng and Chen approximates very well the measured subsidence. The coefficients obtained for each half of the subsidence profile and the square of the coefficient of determination $R^2$ are presented in table 2.

**Table 2**

| Alignment | Left part coefficients | | Right part coefficients | | Coefficient of determination | |
|---|---|---|---|---|---|---|
| | $a_s$ | $b_s$ | $a_d$ | $b_d$ | $R_s^2$ | $R_d^2$ |
| Transversal $T_1$ - $T_1$ | 2,466918 | 1,865147 | 0,243559 | 4,077078 | 0,992548 | 0,998375 |
| Longitudinal $L_{(3\text{-}4)}$ - $L_{(3\text{-}4)}$ | 2,039848 | 2,490492 | 2,437138 | 1,897701 | 0,996767 | 0,998286 |
| Longitudinal $L_5$ - $L_5$ | 2,212215 | 2,605919 | 1,917403 | 1,624931 | 0,997625 | 0,995918 |
| Longitudinal $L_6$ - $L_6$ | 3,303316 | 1,938924 | 2,346315 | 2,064628 | 0,997932 | 0,998539 |

## 4. Conclusions

In our case the surface subsidence monitoring at the Livezeni Mine is made on four alignments which are parallel with the direction of the seam respectively with his inclination.

In these alignments were performed two measurements (the basic measurement and a second measurement, performed after 6 months to capture the movement of land), using GPS technology, RTK method.

This method of monitoring the subsidence phenomenon can be easily applied in places where land topography permits. This method can also be applied using a total station but is a little more complicated.

Even if the RTK method is easy to apply, it presents some disadvantages including (perhaps most important are): high purchase price of this technology, a slightly lower accuracy than with conventional methods (leveling, etc.). Since by this method, the benchmarks which forms the alignments were not materialized, the horizontal displacement could not be determined.

In the present study, for the statistical approximation of the measurements at the Livezeni Mine (using the GPS technology - RTK method) has been used the profile function developed by Peng and Chen in 1981. This profile function can be applied only for half of the subsidence profile, starting from the maximum subsidence to zero. In our case this profile function was applied twice, for the left and right side of the subsidence profile. Applied in this way, for the approximation of the measurements made on the four alignments from the Livezeni Mine, the profile function developed by Peng and Chen led to the following results:

- for the transversal alignment $T_1 - T_1$ – the square of the coefficient of determination for each half of the subsidence profile are: $R_s^2$ = 0,993 and $R_d^2$ = 0,998;
- for the longitudinal alignment $L_{(3\text{-}4)} - L_{(3\text{-}4)}$ – the square of the coefficient of determination for each half of the subsidence profile are: $R_s^2$ = 0,997 and $R_d^2$ = 0,998;
- for the longitudinal alignment $L_5 - L_5$ – the square of the coefficient of determination for each half of the subsidence profile are: $R_s^2$ = 0,998 and $R_d^2$ = 0,996;
- for the longitudinal alignment $L_6 - L_6$ – the square of the coefficient of determination for each half of the subsidence profile are: $R_s^2$ = 0,998 and $R_d^2$ = 0,999;

Therefore the profile function developed by Peng and Chen gives very good results.

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