DRAFT REPORT-6

ON

SCIENTIFIC STUDY FOR PREDICTION OF SUBSIDENCE AND ESTIMATION OF SURFACE STRAIN VALUES BY 3D NUMERICAL MODELLING FOR RK-6, RK-NT, RK-7, RK-8, AND SRP OC II PROJECTS OF SRIRAMPUR AREA, SCCL.

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Scientific Study for Prediction of Subsidence and Estimation of Surface Strain Values by 3D Numerical Modelling for RK-6, RK-NT, RK-7, RK-8, and SRP OC II Projects of Srirampur Area, SCCL.

1. Introduction

Ravindra Khani-6 incline mine is situated on east side of Kazipet-Ballarshah Railway line at about 12 kms towards south from Mancherial Railway station, north central part of Somagudem-Indaram coal belt closely to the north of Mancherial Chennur highway NH-16 and covers an area of 3.06 sq.km. The block is lying between latitude N18^0 51’ 53” to N18^0 52’ 48” and longitude E79^0 30’ 41” to E79^0 31’ 24”. The block is covered by Barakar formation. The mine is located at a distance of about 260 km from the office of the Directorate, Southern Central Zone, Hyderabad.

Another mines of Srirampur area which is taken for subsidence study is the RK 7 incline which is located in the north central part of Somagudem-Indaram coal belt close to the north of Mancherial Chennur highway NH-16 and covers an area of 4.51 sq.km. The block is lying between latitude N18^0 15’ 25” to N18^0 55 ' and longitude E79^0 30’ to E79^0 32’. The block is covered by Barakar formation. The mine was opened on 30.04.1975. There is a total of 8 seams present in this block viz, 1A, 1, 2B, 2A, 2, 3, 4, 5. Out of the 8 seams, 6 seams viz, 1A, 1, 2B, 2A, 2, 4, are working in RK NT & RK 7 and other two seams, namely 3 and 5 seams are not workable due to low thickness. In the block of RK 7 Incline, 1 & 1A seams are being worked by RKNT Incline. The remaining workable seams of 2B, 2A, 2 and 4 are being worked by RK 7 incline. The average gradient of all seams is 1 in 4.2. Total mine take area is 450.97Ha, in which forest land is 396.19 Ha and acquired land is 54.78 Ha. There are no surface features within the mine boundary and is forest land only.

Now another mine taken up for study is the Ravindrakhani New Tech Incline (RKNT) which is situated at Srirampur area of SCCL in Adilabad district of Andhra Pradesh in the Godavari valley coal field. Ravindrakhani New Tech Incline Mine covers an area of 855.7 Ha at present i.e., between longitude north 18°50’28” to 18°52’18” latitude, east 79°31’14” to 79°32’54” longitude north of Godavari River in the survey of India topo sheet No. 56N/10 NW. The mine is situated 12 km from the Mancherial Railway Station which is on Kazipet - Ballarshah main railway line. All the leasehold area is above H.F.L. of Godavari River. The direction and average dip of the seams is N 72^{0}30’ E and 1 in 4.2 respectively.

The last mine taken up in the present study is the Ravindrakhani mine no.8 Incline is located in North Deg.18^0-50’-45” (Latitude) East. Deg.79^0-29’-50” (Longitude) North of Godavari River. The mine is situated at 9 kms from Mancherial Railway Station which is on Kazipet-Balarsha Main Railway Line. All the leasehold area is above H.F.L. of Godavari River. The mine was opened on 03.12.1979 by driving a pair of two reverse tunnels in a gradient of 1 in 4 intersecting all the existing seams.

On the surface of the mine, most of the area is leasehold area of the company and little part of the area of land falls under the jurisdiction of reserve forests. The total Geological Reserves of 24.74MT, Mineable reserves of 14.18MT, Extractable reserves of 7.09MT, are as on 30.09.2020 extracted 6.55MT and balance coal reserves is 0.54MT. There exist five seams namely No.2A, 2, 3, 4 and 5 seams.

2. Objective of the study

The objectives of the study are discussed as follows:

- To conduct scientific study for prediction of subsidence values and strain values due to extraction of seams in RK-6, RK-7, RK-8, RKNT and SRP OC II mines of SRP Area to extent of 823.19 Ha (out of 929.29Ha) of forest land of Indaram Mining Lease.
- To estimate the extent of effect on surface features due to mining operations in the mines.
- Provision of detailed subsidence monitoring layout plan and design for constructing the subsidence stations over the specified area of 823.19 Ha.
- Analysis of subsidence, strain (compressive and tensile), tilt and curvature shall be done periodically based on data provided by SCCL.
- Correlation of the field measurements with the predicted values and analyzing the same.

The present study focuses on obtaining the subsidence curves as shown in the Figure 1 for the RK-6, RK-7, RK-8 and RKNT mines for getting the clearance from forest department of Indaram Mining Lease.

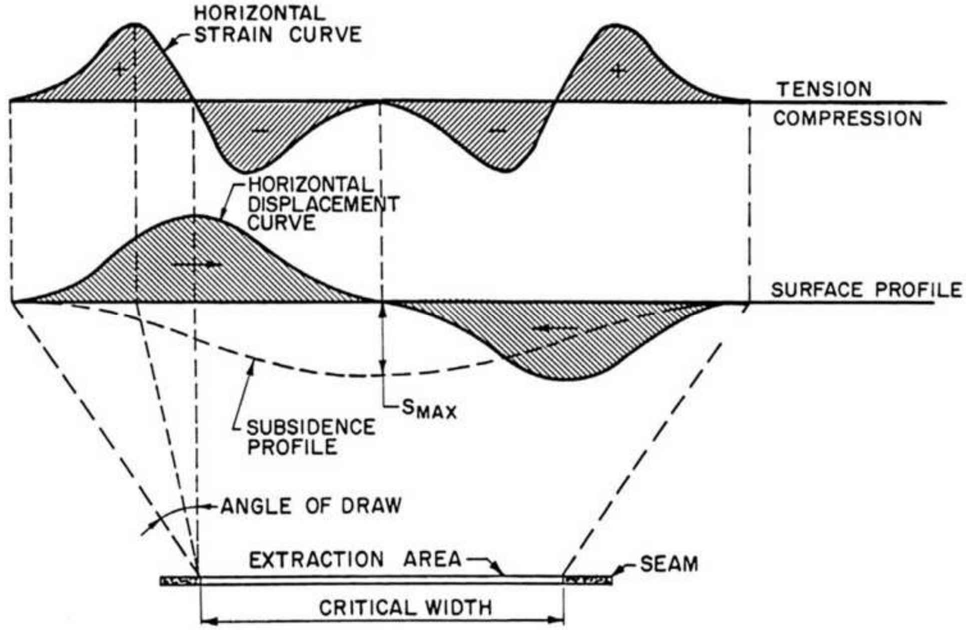


Figure 1(a): Subsidence Parameters.

3. Problem definition

The objective of the work was to perform 3D modeling for subsidence analysis of the Ravindrakhani mines. However, the IIT team and the officials of Srirampur area met on 5th April 2022 and identified the key problem related to the proposed study. The accessible area over the closed mined was surveyed and it was observed that there were no visible surface strains over the mined area. The IIT team also physically witnessed the surface strain measurement stations. Critical sections were identified on the mine plan and 2D section numerical analysis was planned to be conducted thereof. The key mine plan as shown in Figure 1 (b) is supplied by the mine management for performing the subsidence analysis to identify the critical values of strains and obtaining the tilt and curvature profile in Ravindrakhani mines. The detailed subsidence analysis is being done by taking several critical 2D longitudinal cut sections in the abovesaid mines and the section drawings are shown below. The depth of the seam ranges from 820 RL to 750 RL in Section A-A', B-B', C-C', D'-D'', E-E' and F-F' as shown in Figures 1(c-h) respectively. The sections show the multiple seams with details of depillared panels. Numerical modelling by finite element analysis will help us in predicting the subsidence values on the surface of the mines and compare it with the values obtained from subsidence monitoring stations.

All the subsidence parameters are confirmed by obtaining the relevant curves from the numerical simulations for each mine and the angle of draw and angle of break is thereof measured from the strain contours and plotted results.

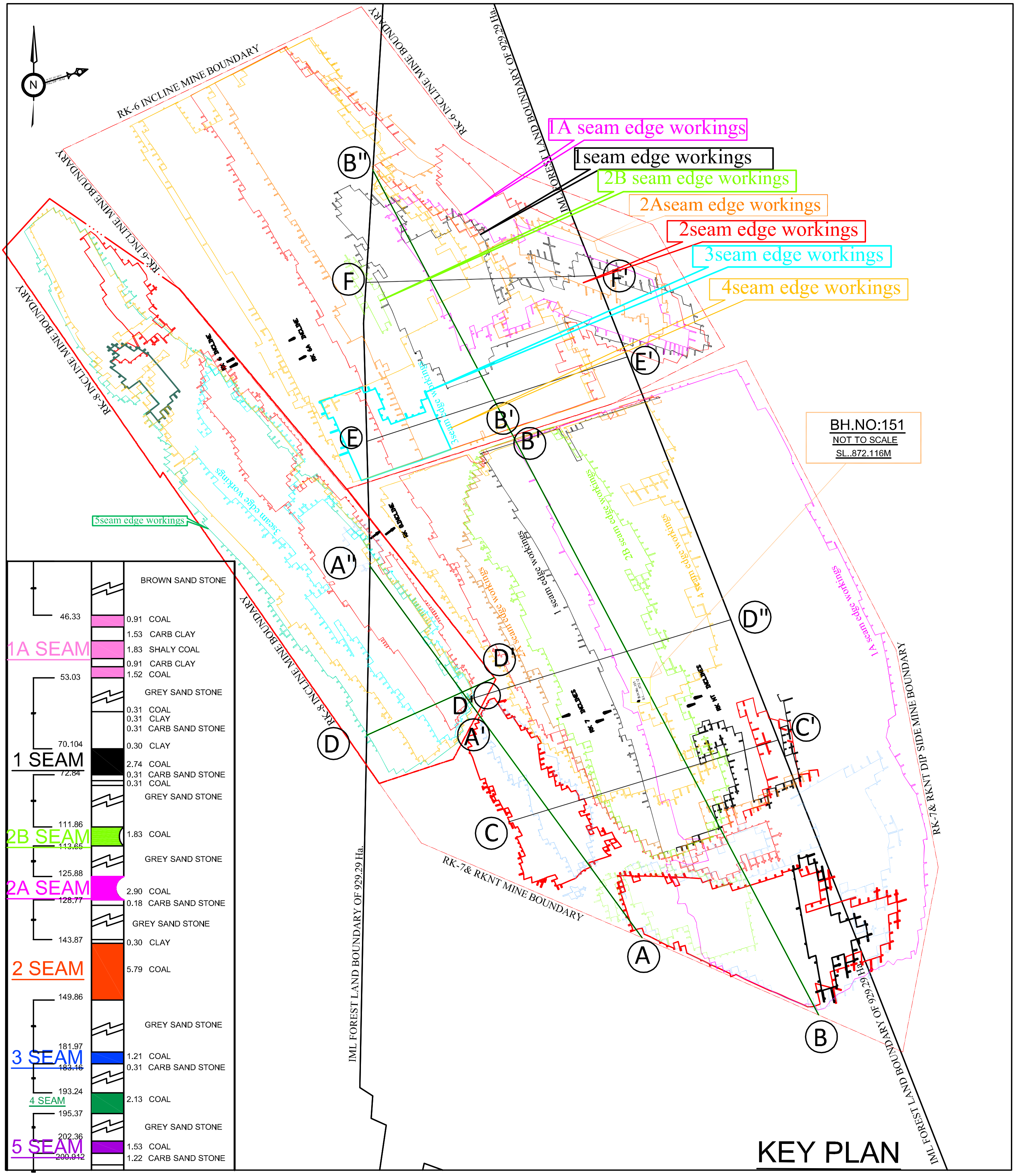


Figure 1(b): Key plan of the mine showing the cut sections taken for analysis.

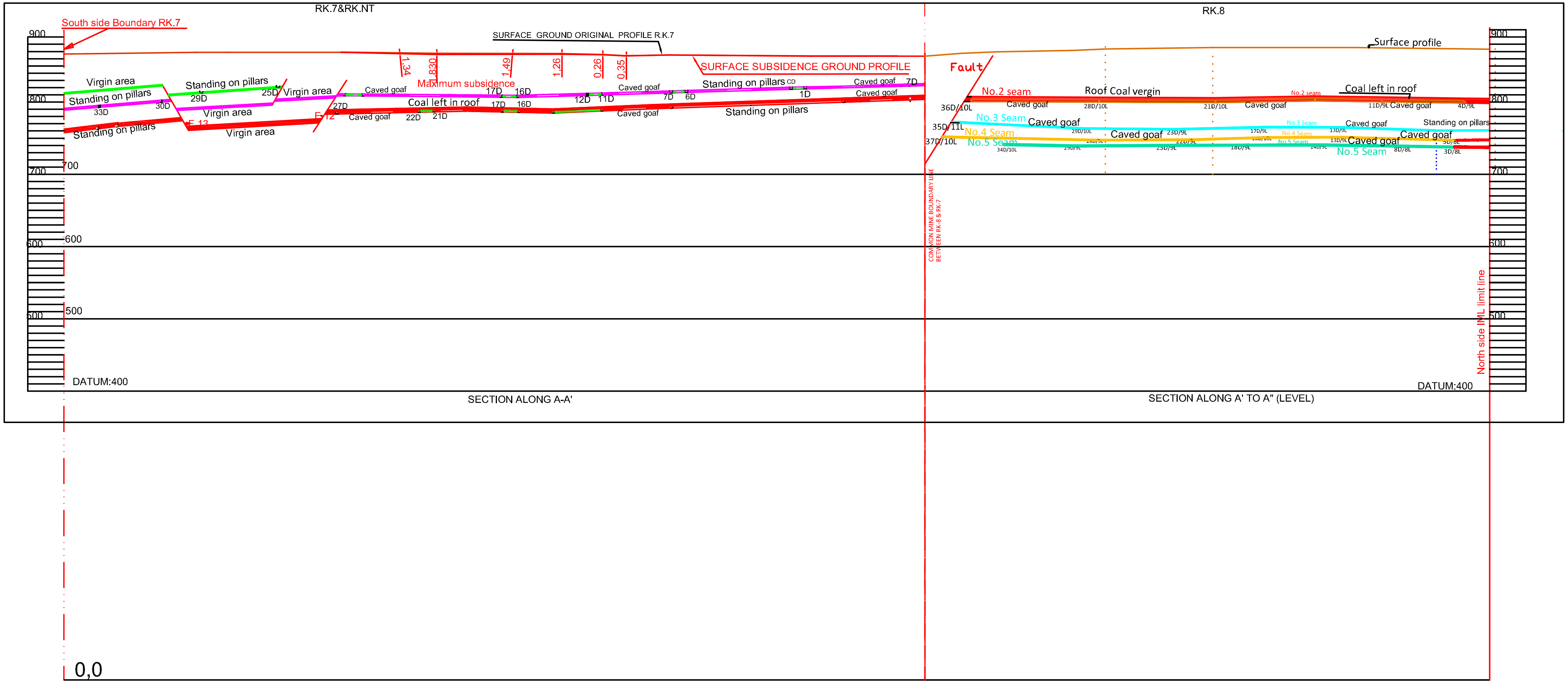


Figure 1(c): Section A-A’ taken in RK-7, RKNT and RK-8 mines.

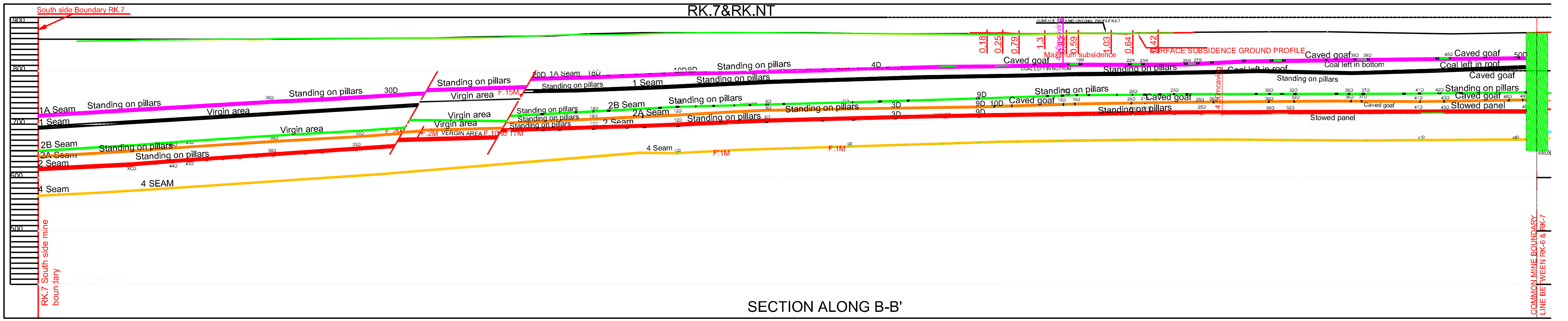


Figure 1(d): Section B-B' taken in RK-7 and RKNT mines.

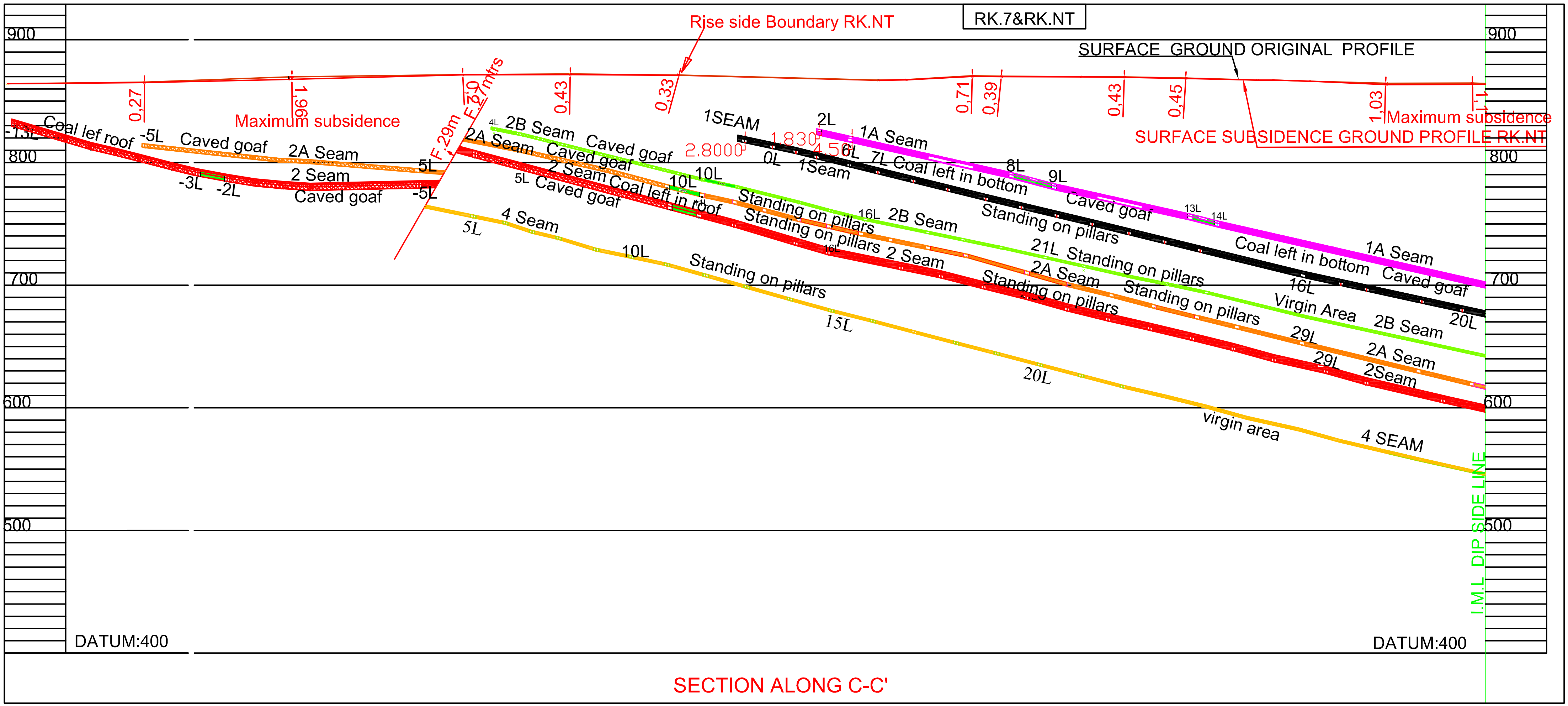


Figure 1(e): Section C-C' taken in RK-7 and RKNT mines.

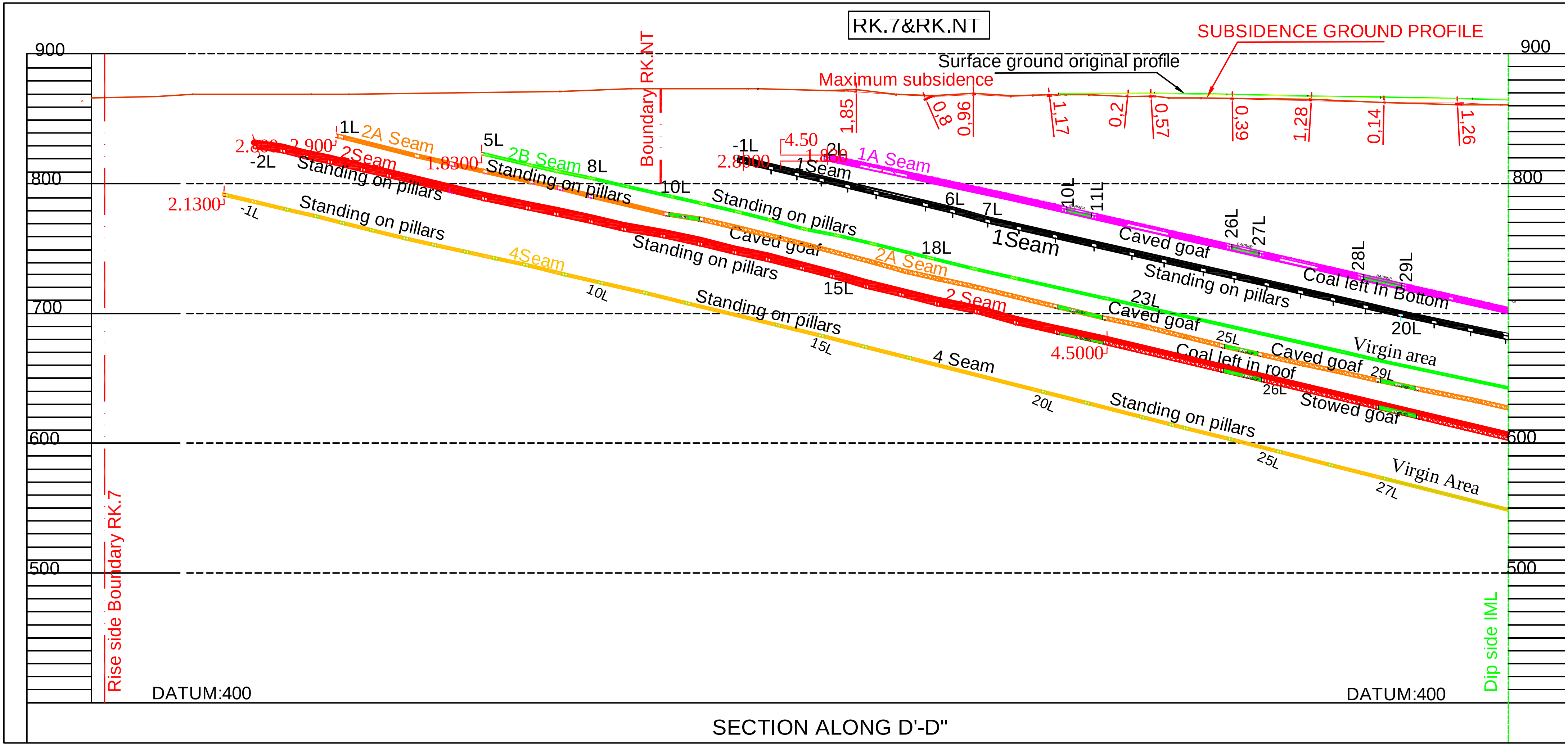


Figure 1(f): Section D'-D" taken in RK-7 and RKNT.

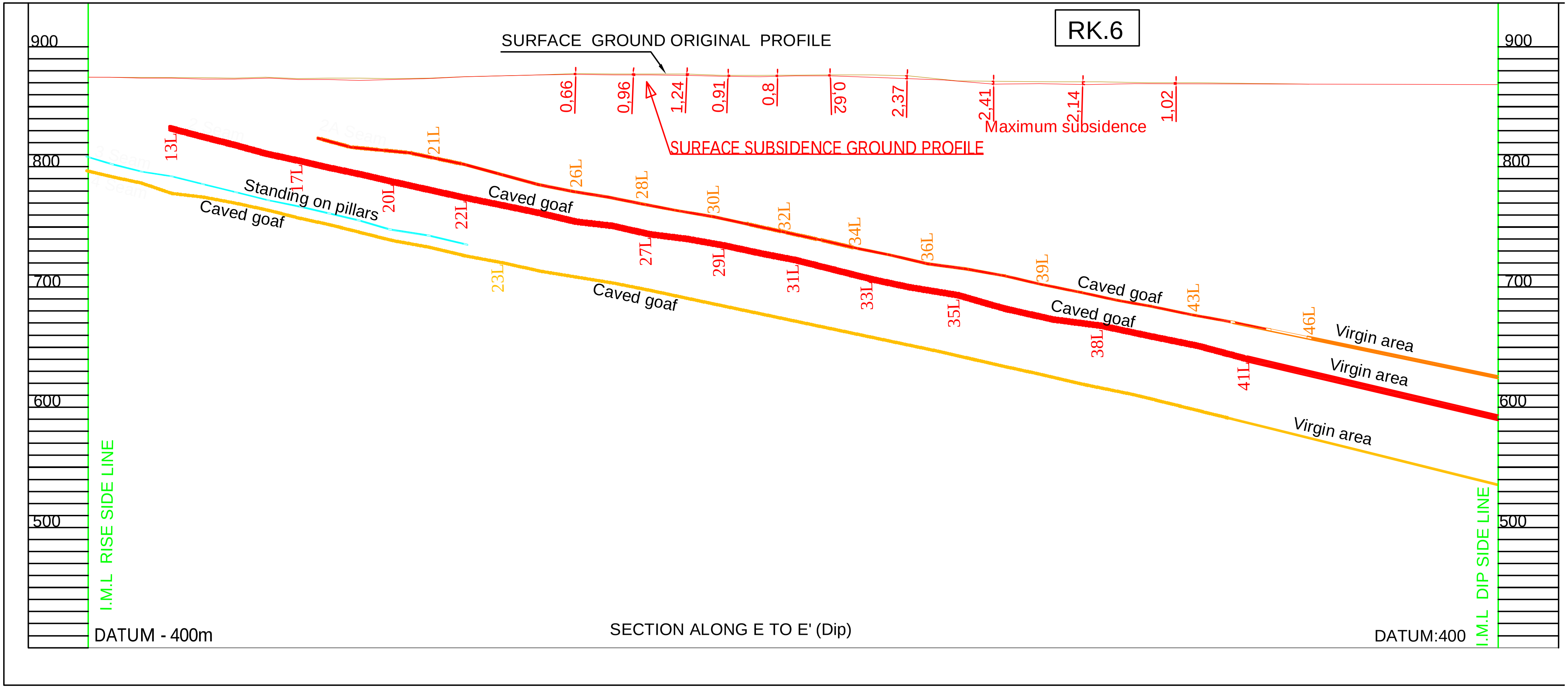


Figure 1(g): Section E-E’ taken in RK-6 mines.

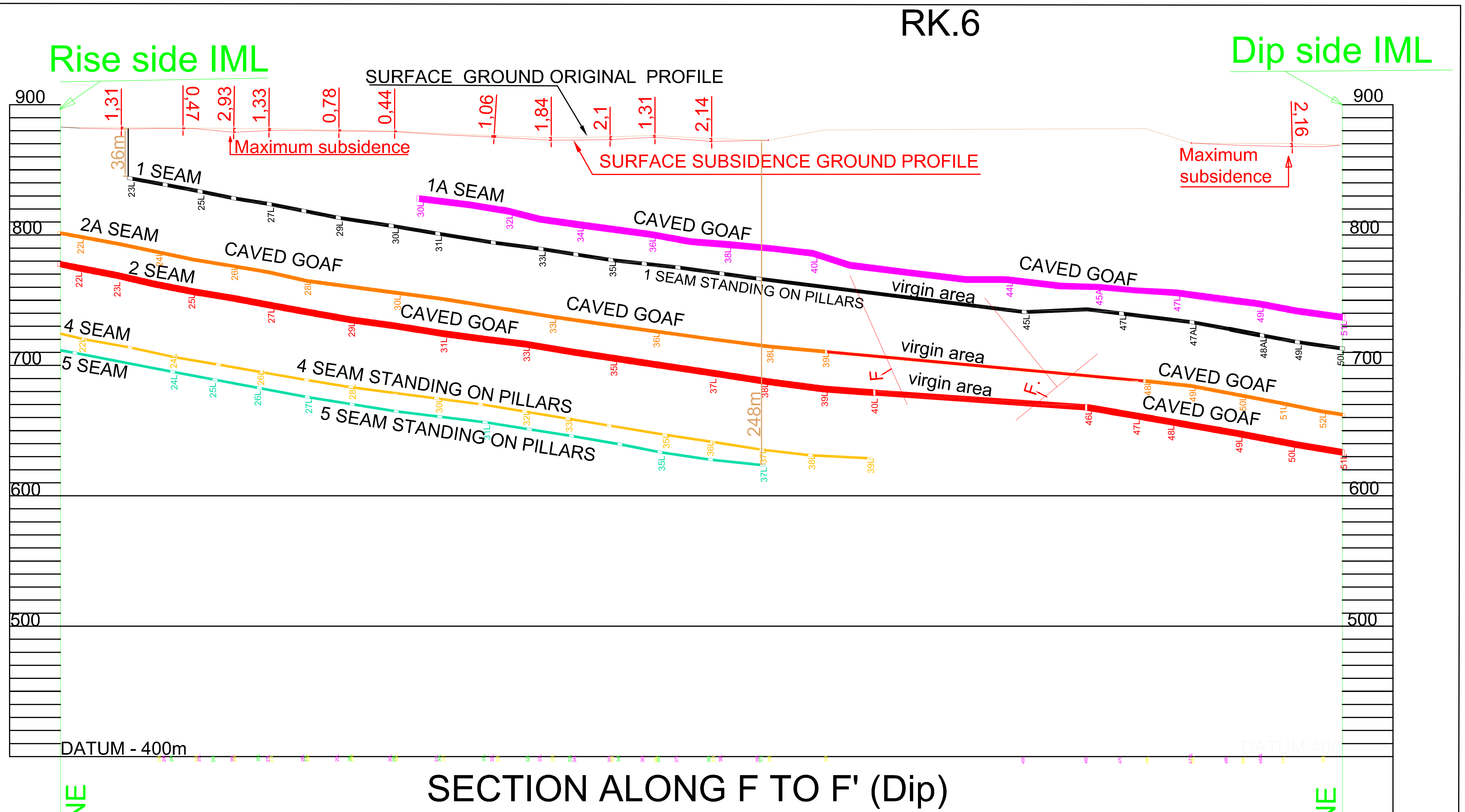


Figure 1(h): Section F-F’ taken in RK-6.

4. Finite element simulation for subsidence analysis of Ravindrakhani mines (RK-7, RKNT, RK-8 and RK-6 mines)

Three two-dimensional (2D) finite element (FE) models were developed similar to the longitudinal cross-sections of the Ravindrakhani mines showcasing the developed pillars and depillared panels with caved goafs as shown in Figures 1(c-h). The sectional views were given to the IIT team to perform the required analysis by the mine management. The model was developed by using the finite element package software, Abaqus 2021.

The model consists of multiple coal seams and sandstone as the host rock. The gradient of the coal seam is 1 in 4.2. All the mines of Ravindrakhani, i.e., RK-6, RK-7, RKNT and RK-8 mines were excavated by bord and pillar method of mining. The model has been developed in bord and pillar form and depillaring of panels similar to the drawing given by mine management.

The model is assessed under gravitational load and was given 9.81 m/s^2 acceleration in negative y-direction. The degrees of freedom in the side walls and the bottom layer in sandstone is restricted to $U_x = U_y = U_z = 0$. The mesh was generated with CPE4R element type which is a 4-node bilinear plane strain quadrilateral element with reduced integration and hour glassing controls to perform a static general plane strain analysis.

The Mohr Coloumb constitutive relations are used for defining the material behaviour the action of gravitational load. The material properties taken for the plane strain analysis are given in Table 1.

Table 1: Mechanical properties of rocks used in finite element analyses.

Rock Type	Density, ρ (kg/m^3)	Elastic Modulus, E (GPa)	Poisson's ratio, υ	Angle of friction, ϕ	Dilation Angle, ψ	Cohesive Strength, c (MPa)
Sandstone	2220	5	0.20	30	10	2
Coal	1400	4	0.28	40	10	4

5. Results and Discussion of Subsidence Analysis in Ravindrakhani mines.

The stress and strain responses are obtained for each section for the subsidence analysis.

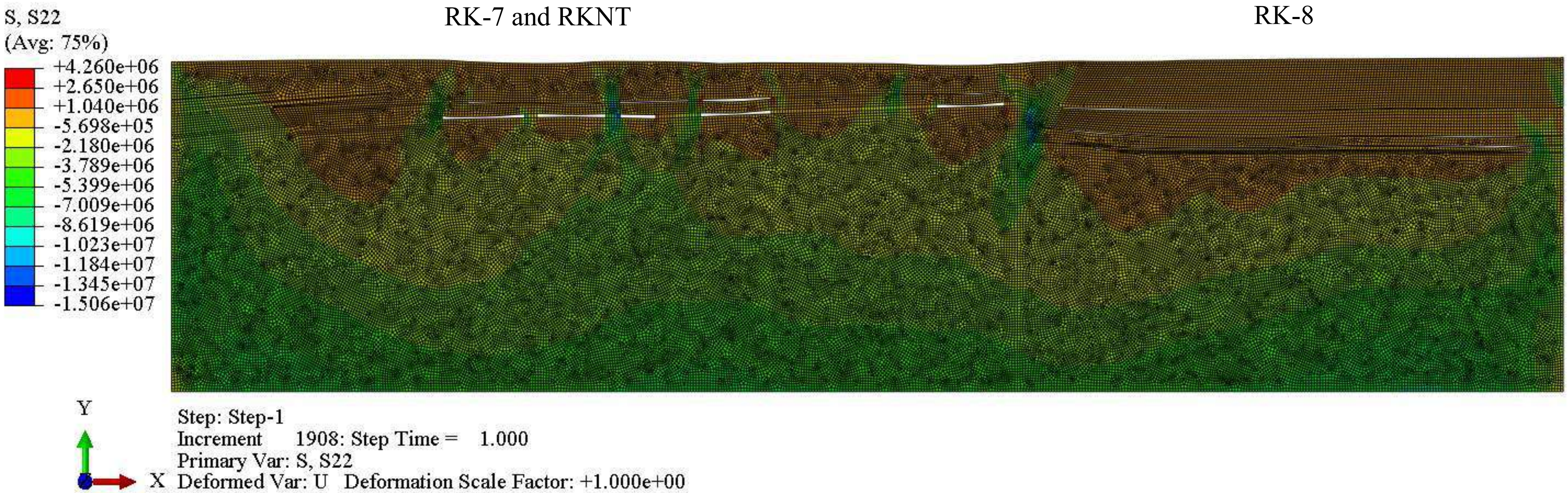


Figure 2: Stress contours of section A-A’ in y-direction under the action of gravitational load (All values in SI unit, S22 is in Pa).

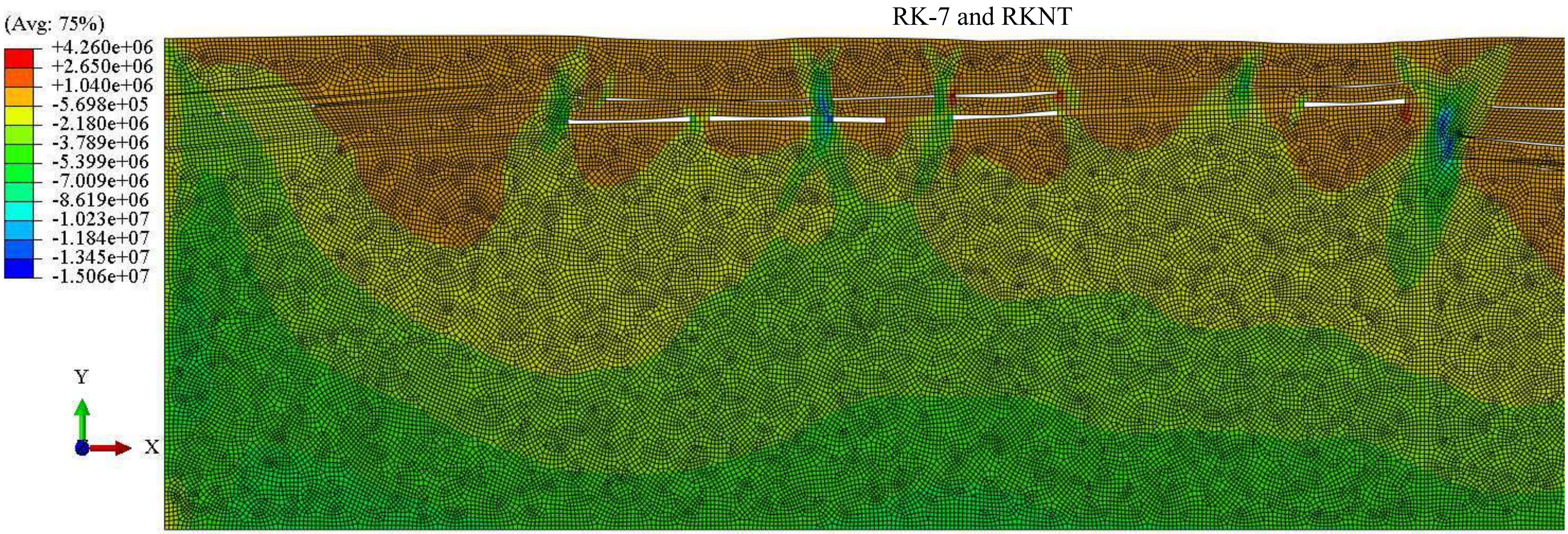


Figure 3: Enlarged view of the stress contours for RK-7 and RK-NT mines of section A-A' in y-direction under the action of gravitational load (All values in SI unit, S22 is in Pa).

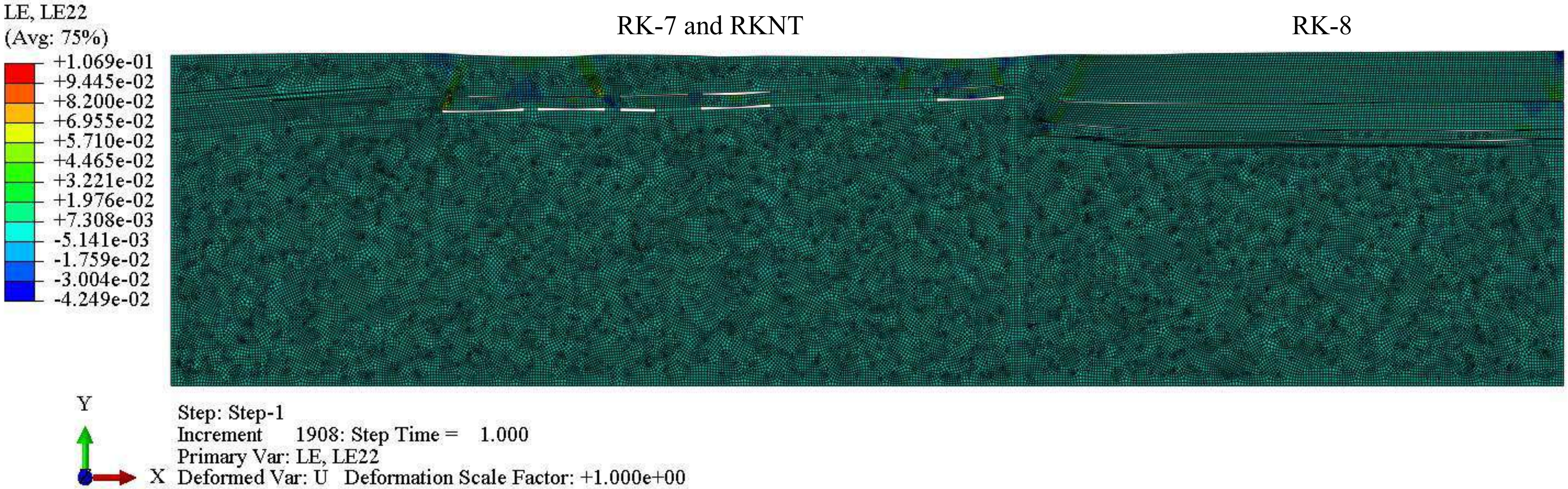


Figure 4: Strain contours of section A-A' in y-direction under the action of gravitational load (All values in SI unit, LE22 is in m/m).

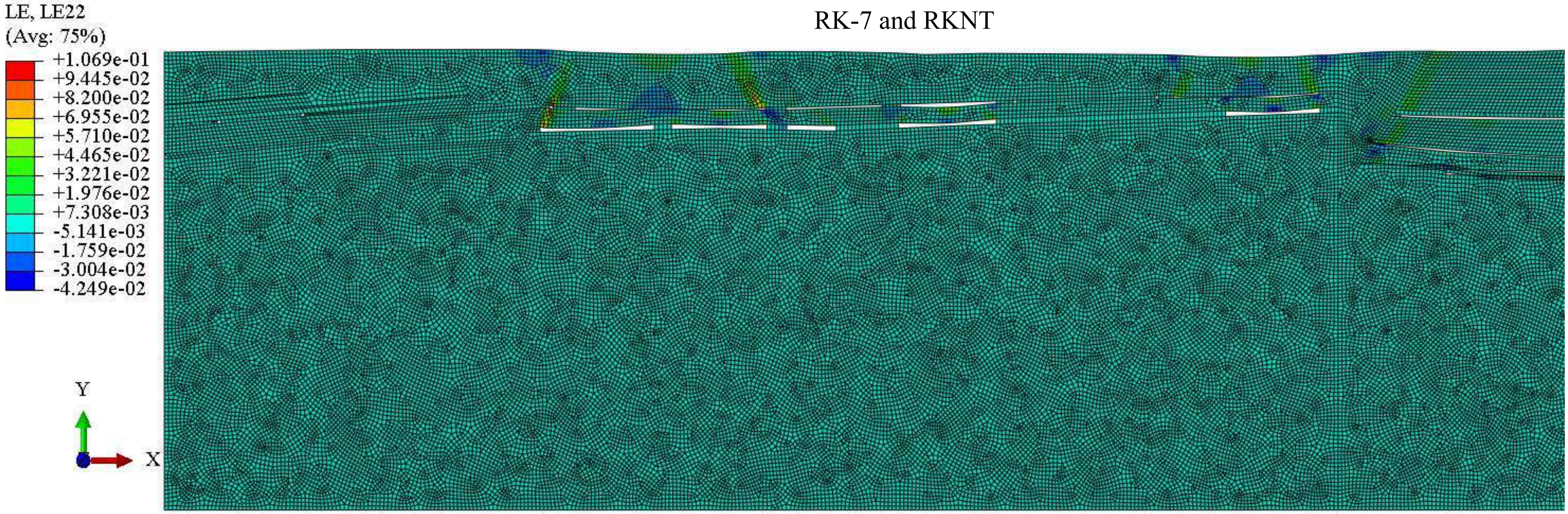


Figure 5: Enlarged view of the strain contours for RK-7 and RK-NT mines of section A-A' in y-direction under the action of gravitational load (All values in SI unit, LE22 is in m/m).

Table 2: Subsidence values generated on the surface of RK-7, RKNT and RK-8 underground mines in Section A-A' from numerical simulations.

Mine	Sections	Point taken from surface				
		Maximum Subsidence Value, *d* (m)		Maximum Strain Values, ε (mm/m)	Angle of Draw (°)	Angle of Break (°)
		Measuring Stations	Numerical Simulations			
RK-7 and RKNT	A-A'	1.83	1.63	5.57	29.62	18
RK-8		-	2.76	9.71	34.92	18.23

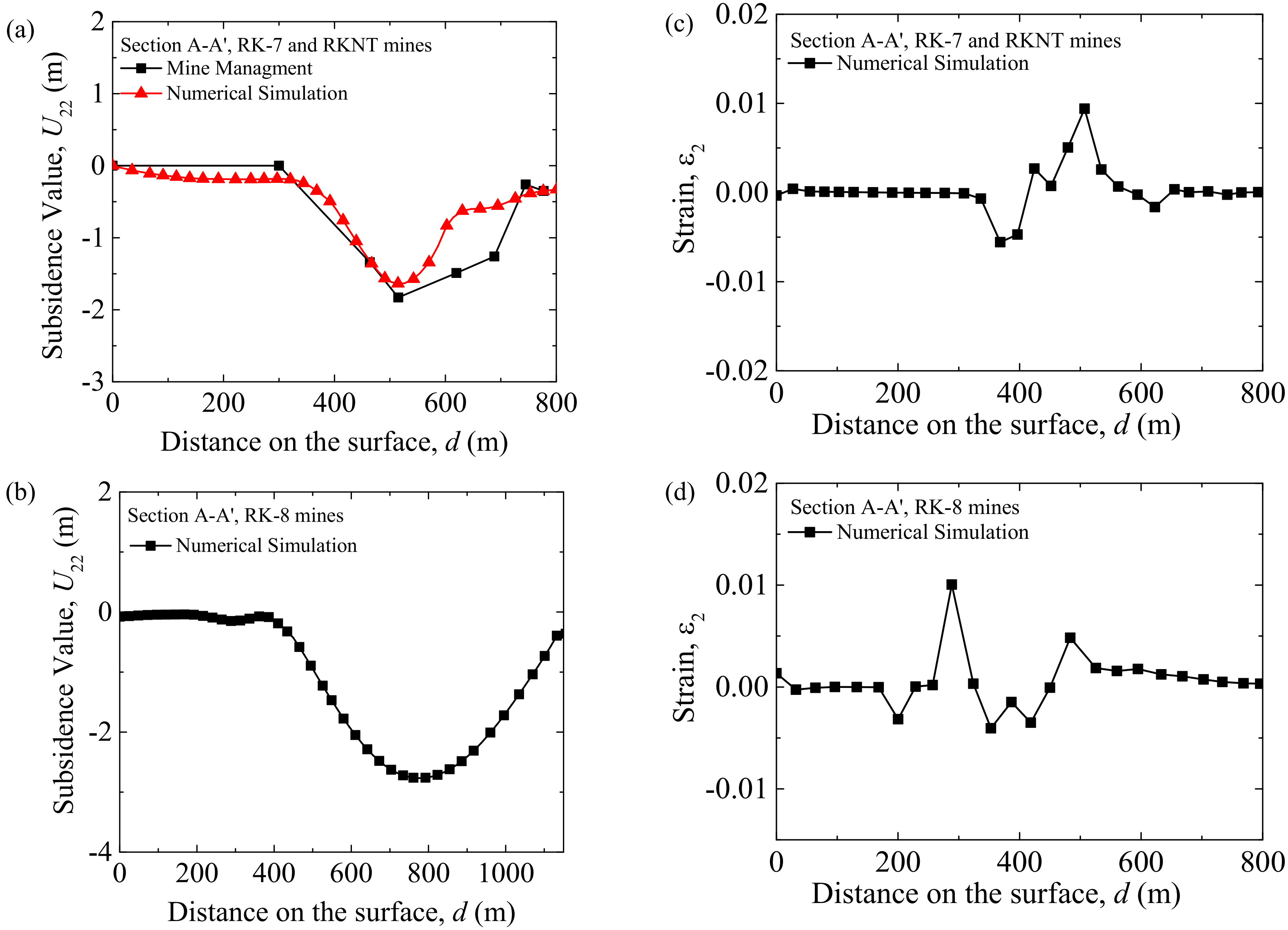


Figure 6: (a) Subsidence profile, (b) Curvature profile on the surface of RK-7 and RKNT mines and (c) Subsidence profile, (d) Curvature profile on the surface of RK-8 mines for Section A-A'.

Since there are multiple seams in a particular location and a group of seams belongs to a particular mine, Figures 2 and 4 show the stress and strain contours obtained from the FE analysis of section A-A' for subsidence analysis under gravitational load for RK-7, RKNT and RK-8 mines. Figures 3 and 5 show the Enlarged view of stress and strain contours obtained from the FE analysis of section A-A' for RK-7 and RKNT mines. It is noted from the section that the maximum subsidence occurred on the surface of RK-7 and RKNT mines are almost equal to the values measured from subsidence measuring stations installed over the surface of RK-7 and RKNT mines, i.e., 1.63 m from the numerical simulations and 1.83 m from the subsidence measuring stations. The comparative graph of the subsidence from the numerical study and from the subsidence measuring stations as provided by the mine management is shown in Figure 6(a). From the strain contours obtained from numerical simulation and physical data from the measuring stations, the angle of draw and angle of break for RK-7 and RKNT mines are found to be 29.62 degree and 18 degrees, respectively. The curvature and tilt profiles with surface strains generated on the surface is also shown in Figure 6(b) for RK-7 and RKNT mines.

The subsidence over the surface of RK-8 mines is found to be 2.76 m and the subsidence profile is shown in Figure 6(c). The angle of draw and angle of break for the RK-8 mines were found to be 34.92 degree and `18.23 degrees, respectively. The curvature and tilt profiles with surface strains generated on the surface are also shown in Figure 6(d) for RK-8 mines.

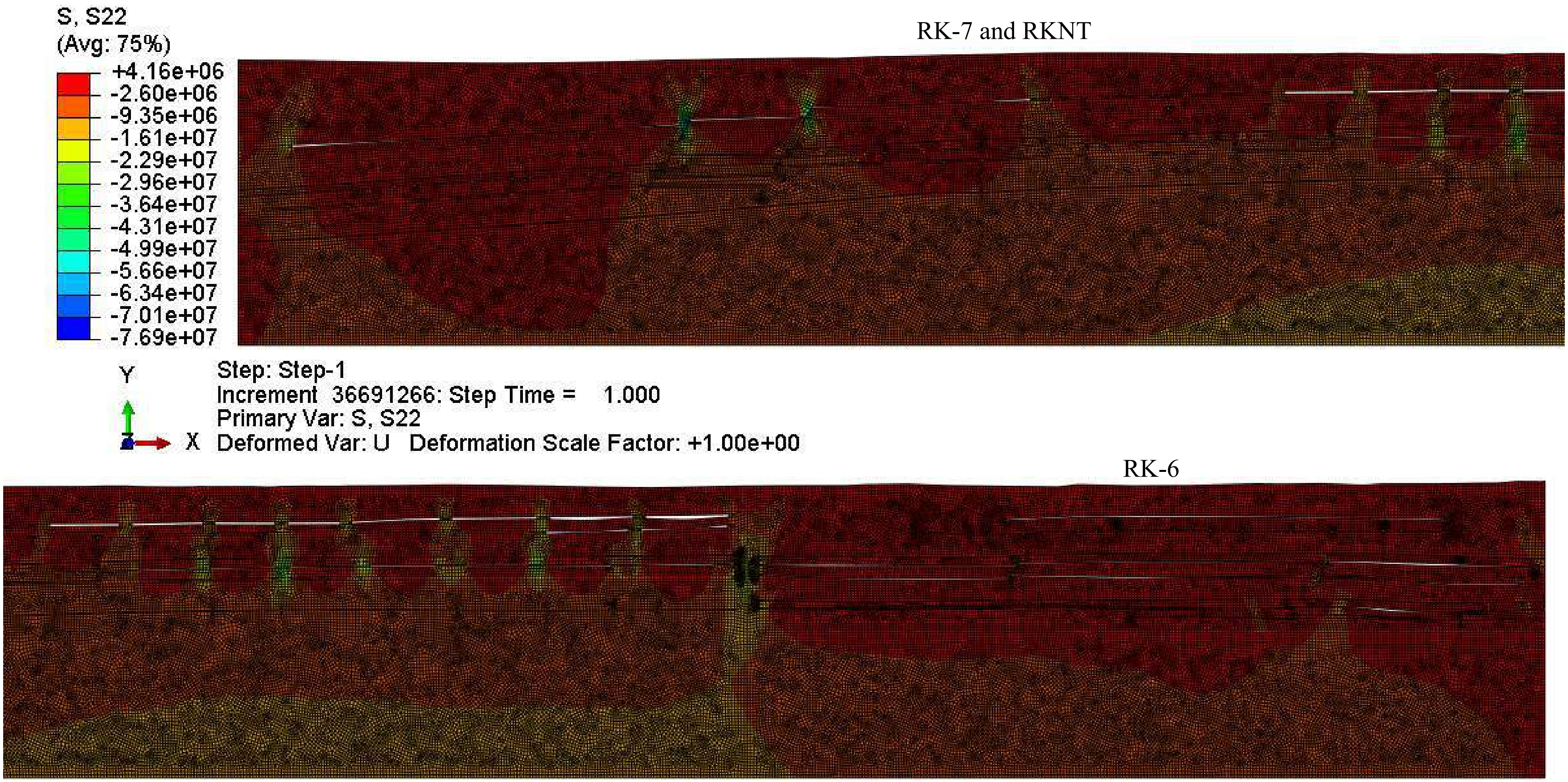


Figure 7: Enlarged view of the stress contours for RK-7, RK-NT and RK-6 mines of section B-B' in y-direction under the action of gravitational load (All values in SI unit, S22 is in Pa).

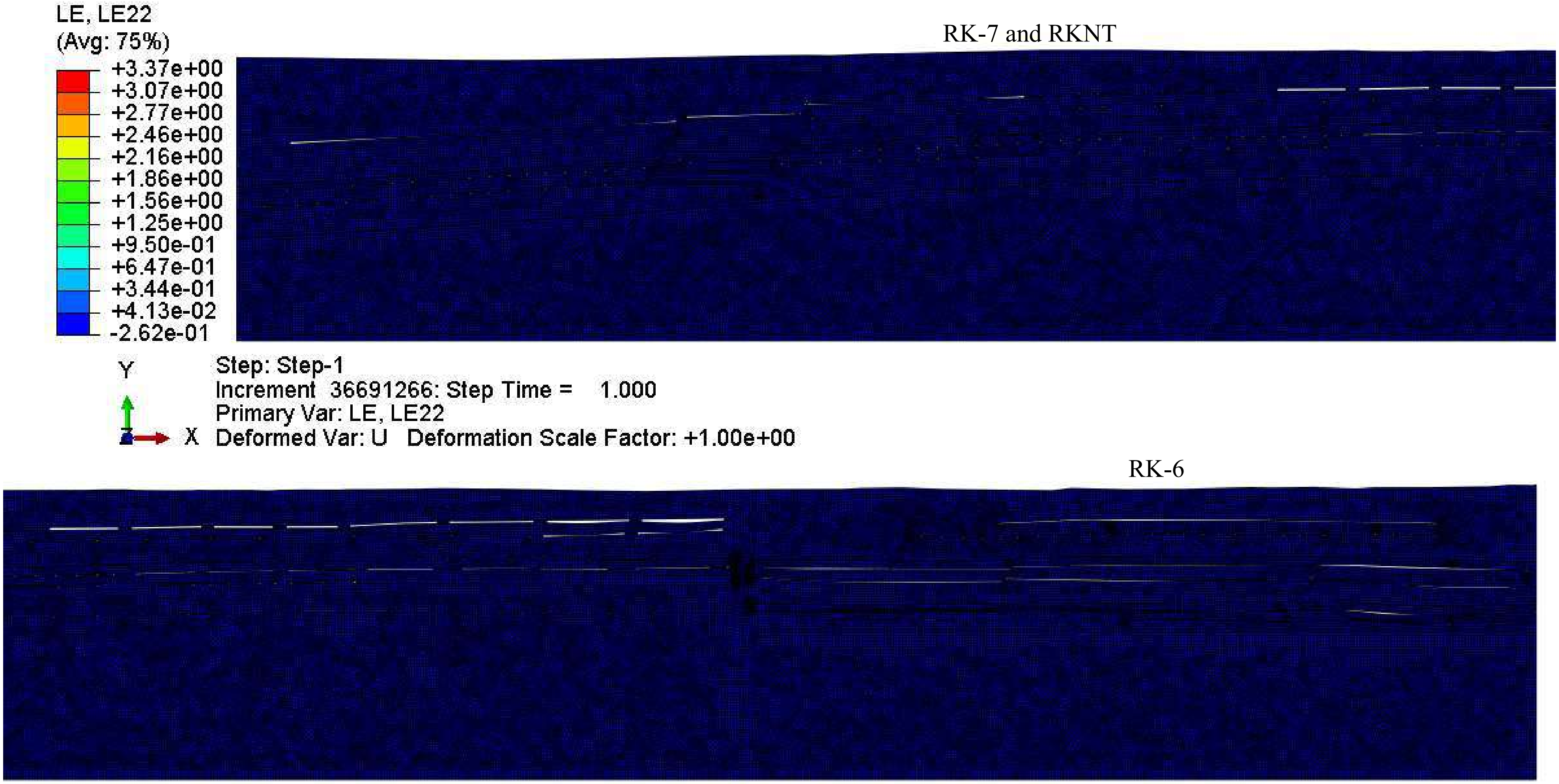


Figure 8: Enlarged view of the strain contours for RK-7, RK-NT and RK-6 mines of section B-B' in y-direction under the action of gravitational load (All values in SI unit, LE22 is in m/m).

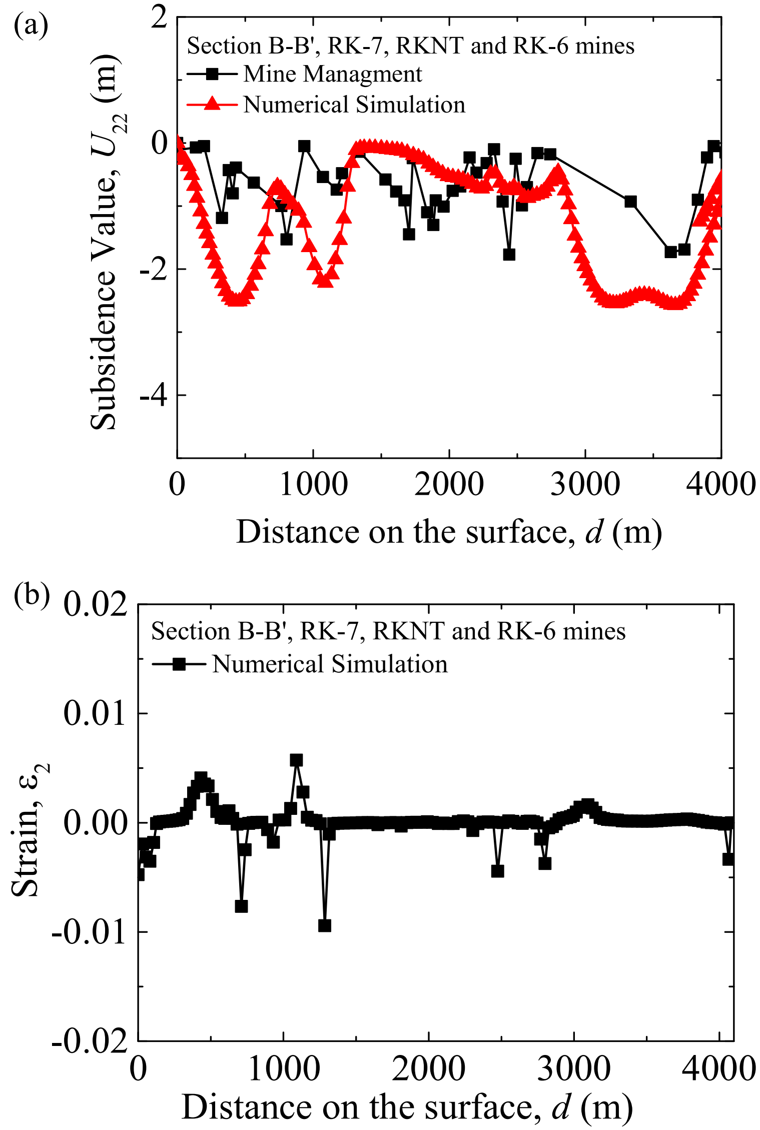


Figure 9: (a) Subsidence profile, (b) Curvature profile on the surface of RK-7, RKNT and RK-6 mines for Section B-B’.

Table 3: Subsidence values generated on the surface of RK-7, RKNT and RK-6 underground mines in Section B-B' from numerical simulations.

Mine	Sections	Point taken from surface				
		Maximum Subsidence Value, *d* (m)		Maximum Strain Values, ε (mm/m)	Angle of Draw (°)	Angle of Break (°)
		Measuring Stations	Numerical Simulations			
RK-7 and RKNT	B-B'	1.77	2.54	9.43	24.64	13.22
RK-6		1.73	2.51	3.35	20.65	10

Now, again, Figures 7 and 8 show the stress and strain contours obtained from the FE analysis of section B-B' for subsidence analysis under gravitational load for RK-7, RKNT and RK-6 mines. It is noted from the section that the maximum subsidence occurred on the surface of RK-7 and RKNT mines are on the higher side of the values measured from subsidence measuring stations installed over the surface of RK-7 and RKNT mines, i.e., 2.54 m from the numerical simulations and 1.77 m from the subsidence measuring stations. The comparative graph of the subsidence from the numerical study and from the subsidence measuring stations as provided by the mine management is shown in Figure 9(a). From the strain contours obtained from numerical simulation and physical data from the measuring stations, the angle of draw and angle of break for RK-7 and RKNT mines are found to be 24.64 degree and 13.22 degrees, respectively. While the angle of draw and angle of break for RK-6 mine is found to be 20.65 degree and 10 degrees, respectively. The curvature and tilt profiles with surface strains generated on the surface are also shown in Figure 9(b) for RK-7, RKNT and RK-6 mines.

As the results obtained from the numerical simulation is found to be on higher side of the subsidence data measured from subsidence measuring stations, it is therefore suggested to monitoring of the surface strains may be continued by the mine management as is being done now following DGMS Circular number 4 of 1988.

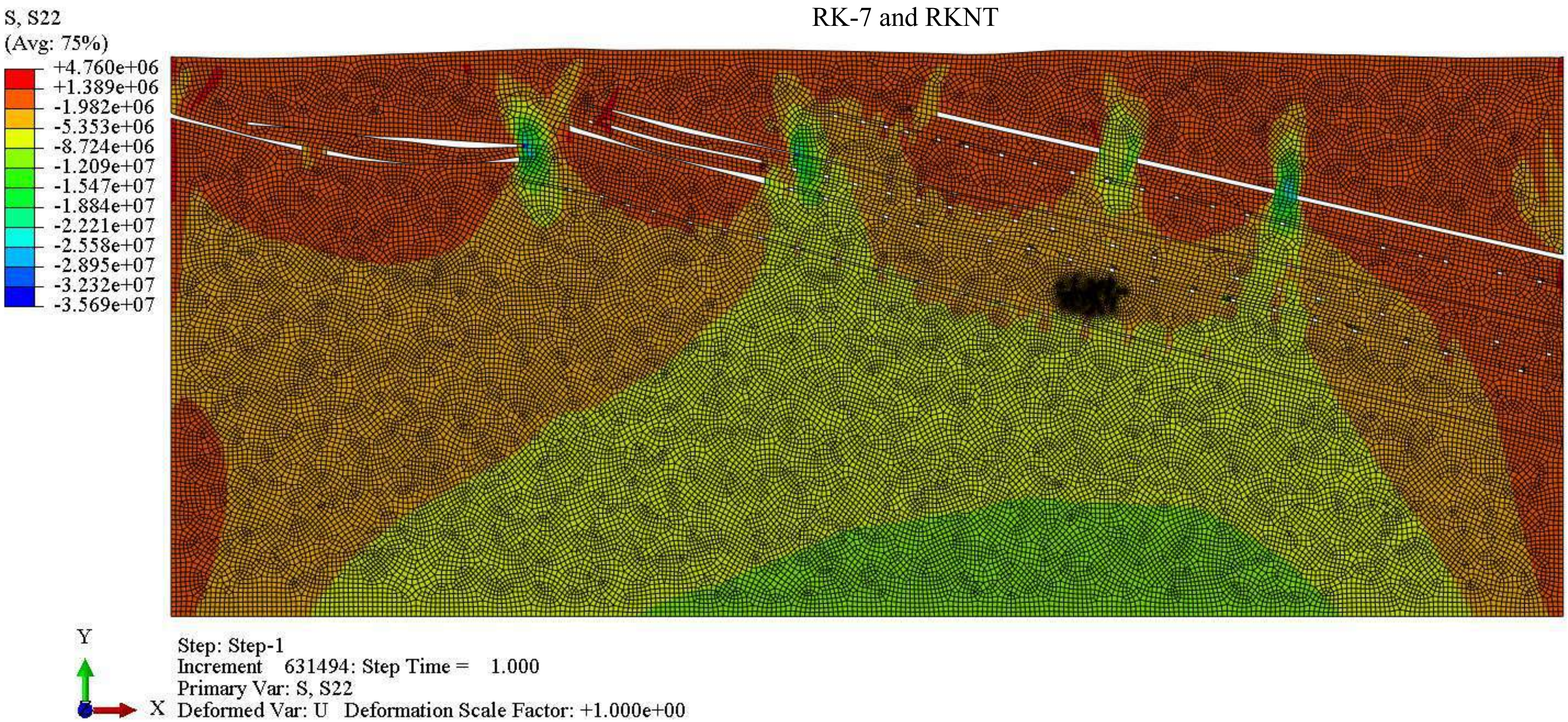


Figure 10: Stress contours for RK-7 and RKNT mines of section C-C' in y-direction under the action of gravitational load (All values in SI unit, S22 is in Pa).

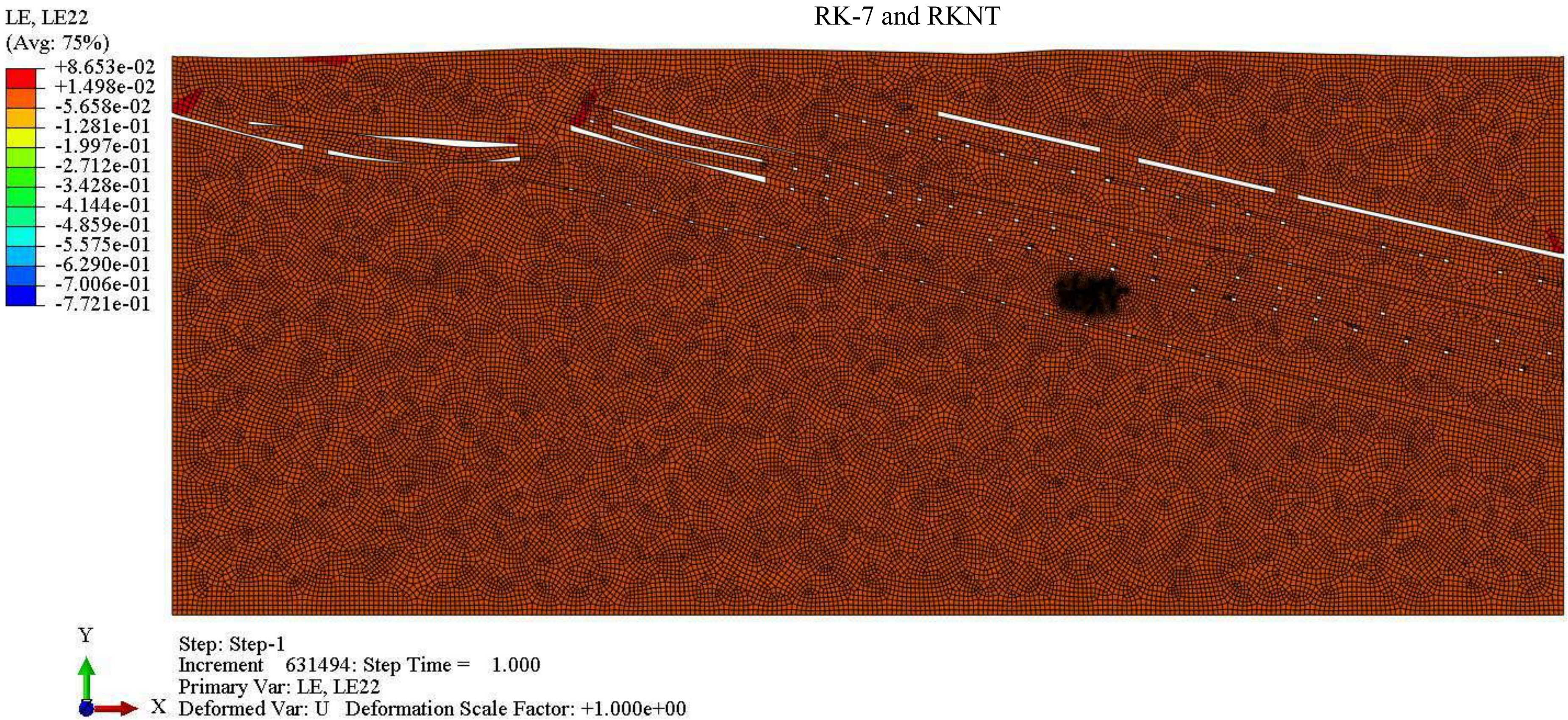


Figure 11: Strain contours for RK-7 and RKNT mines of section C-C' in y-direction under the action of gravitational load (All values in SI unit, LE22 is in m/m).

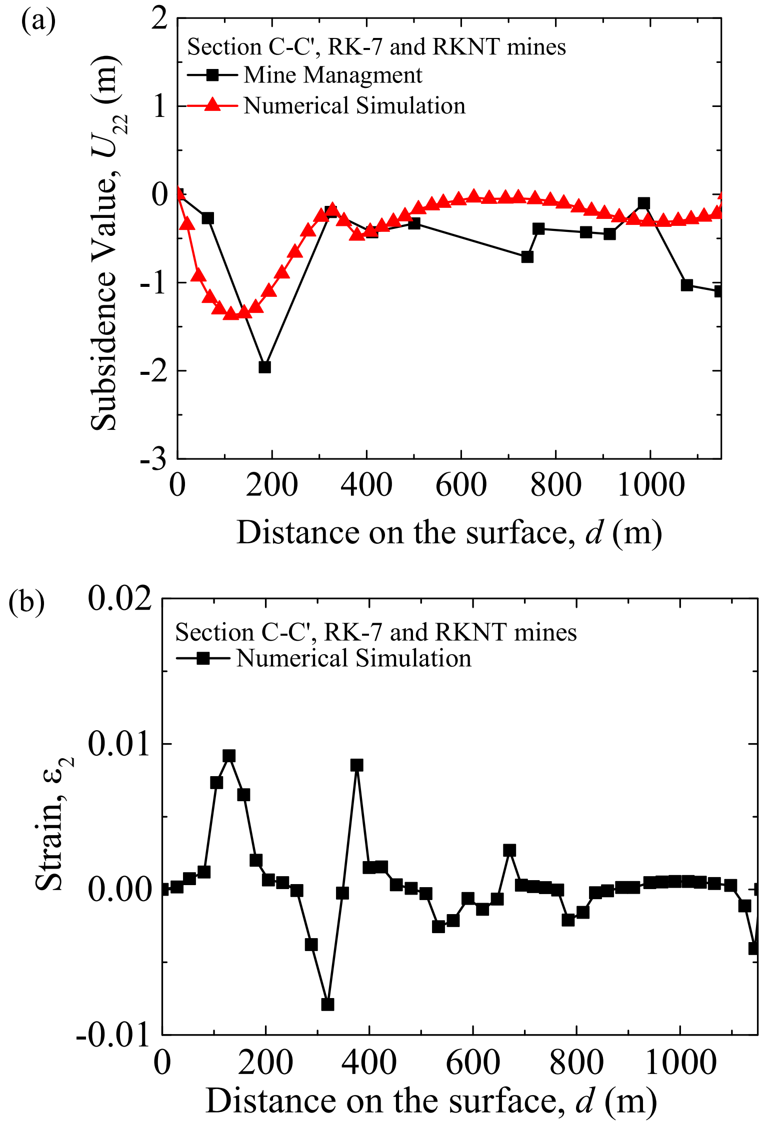


Figure 12: (a) Subsidence profile, (b) Curvature profile on the surface of RK-7 and RKNT mines for Section C-C'.

Figures 10 and 11 show the stress and strain contours obtained from the FE analysis of section C-C' for subsidence analysis under gravitational load for RK-7 and RKNT only. Similar to previous section analysis, it is noted from the numerical simulation that the maximum subsidence occurred on the surface of RK-7 and RKNT mines and is less than the values measured from subsidence measuring stations installed over the surface of RK-7 and RKNT mines, i.e., 1.36 m from the numerical simulations and 1.96 m from the subsidence measuring stations. The comparative graph of the subsidence from the numerical study and from the subsidence measuring stations as provided by the mine management is shown in Figure 12(a). From the strain contours obtained from numerical simulation and physical data from the measuring stations, the angle of draw and angle of break for RK-7 and RKNT mines are found to be 29.50 degree and 19 degrees, respectively. The curvature and tilt profiles with surface strains generated on the surface are also shown in Figure 12(b) for RK-7 and RKNT mines.

Table 4: Subsidence values generated on the surface of RK-7 and RKNT underground mines in Section C-C' from numerical simulations.

Mine	Sections	Point taken from surface				
		Maximum Subsidence Value, *d* (m)		Maximum Strain Values, ε (mm/m)	Angle of Draw (°)	Angle of Break (°)
		Measuring Stations	Numerical Simulations			
RK-7 and RKNT	C-C'	1.96	1.36	7.91	29.50	19

RK-7 and RKNT

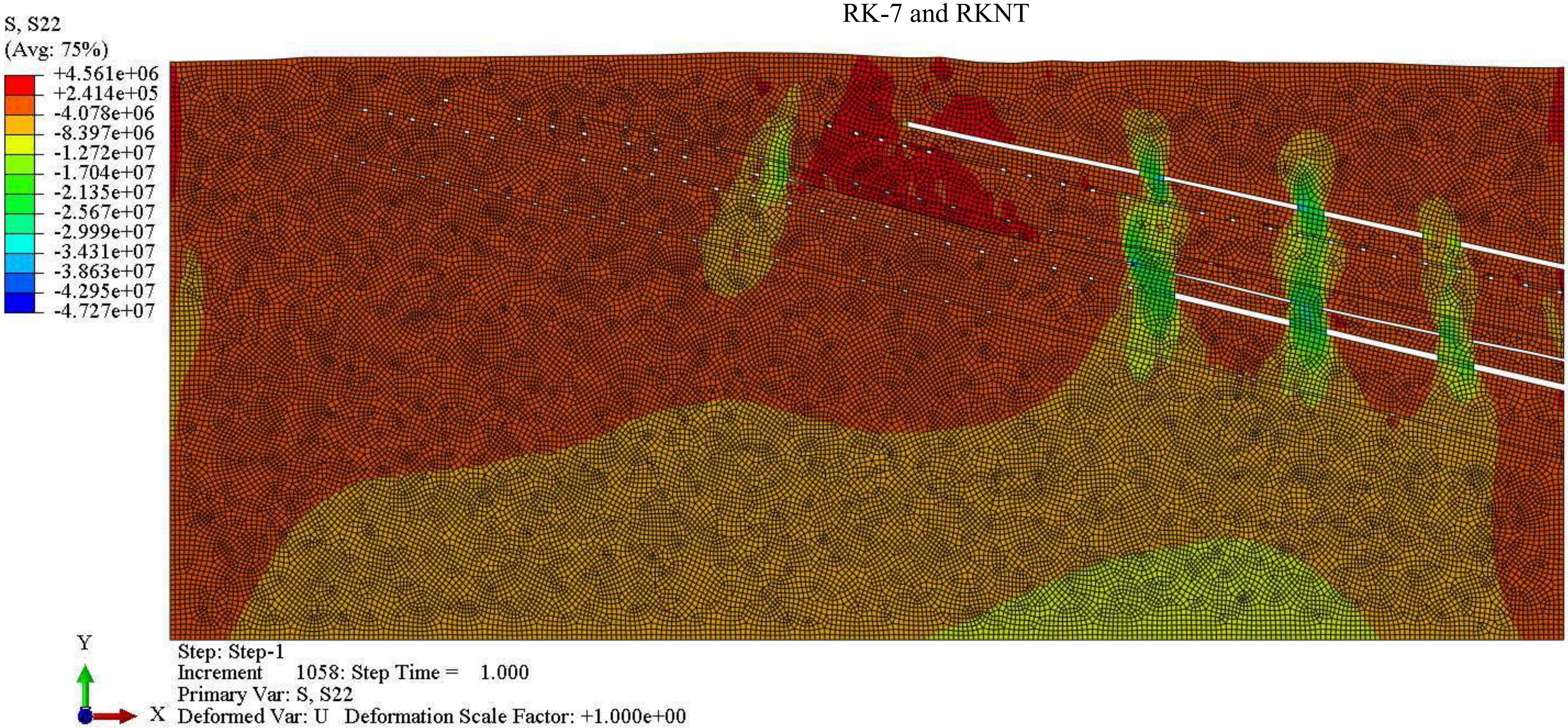


Figure 13: Stress contours for RK-7 and RKNT mines of section D'-D" in y-direction under the action of gravitational load (All values in SI unit, S22 is in Pa).

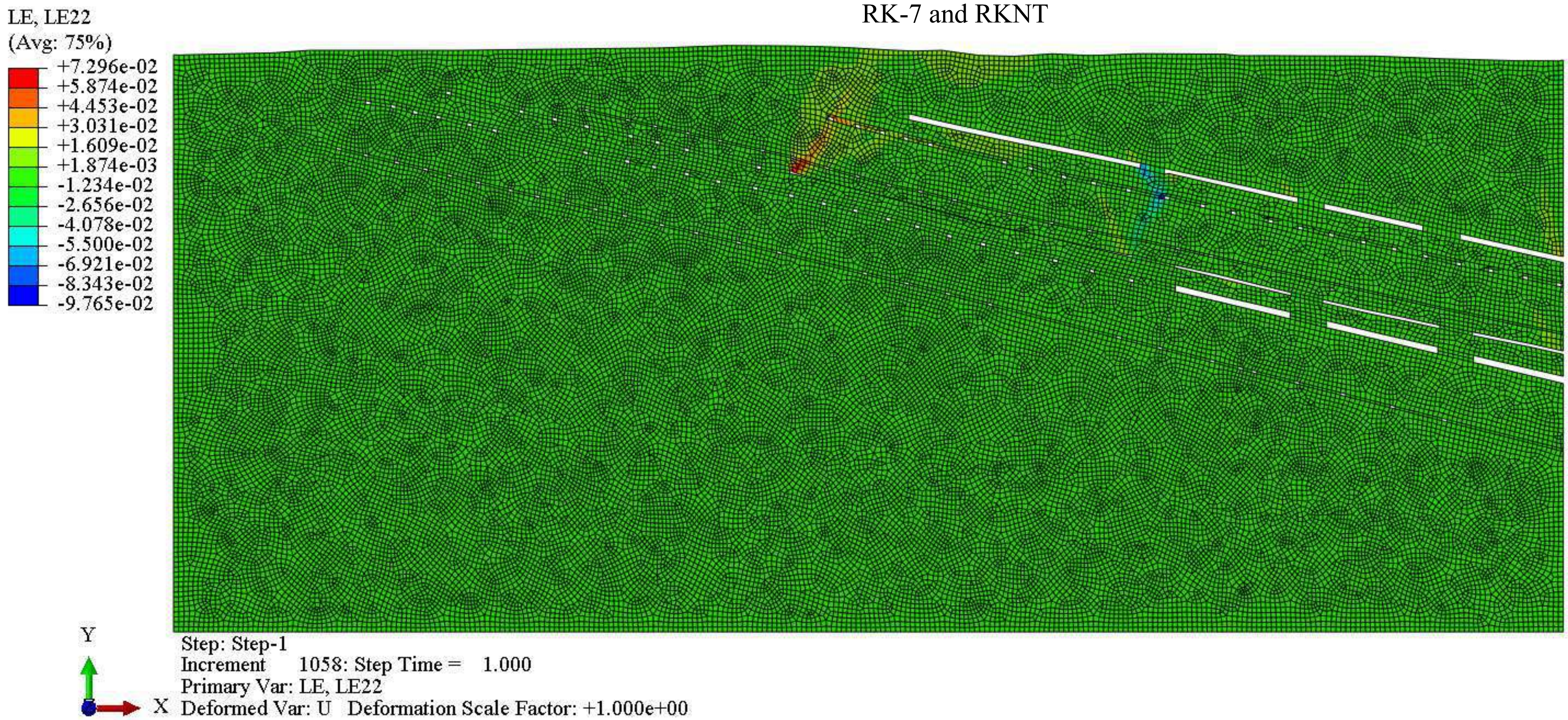


Figure 14: Strain contours for RK-7 and RKNT mines of section D'-D" in y-direction under the action of gravitational load (All values in SI unit, LE22 is in m/m).

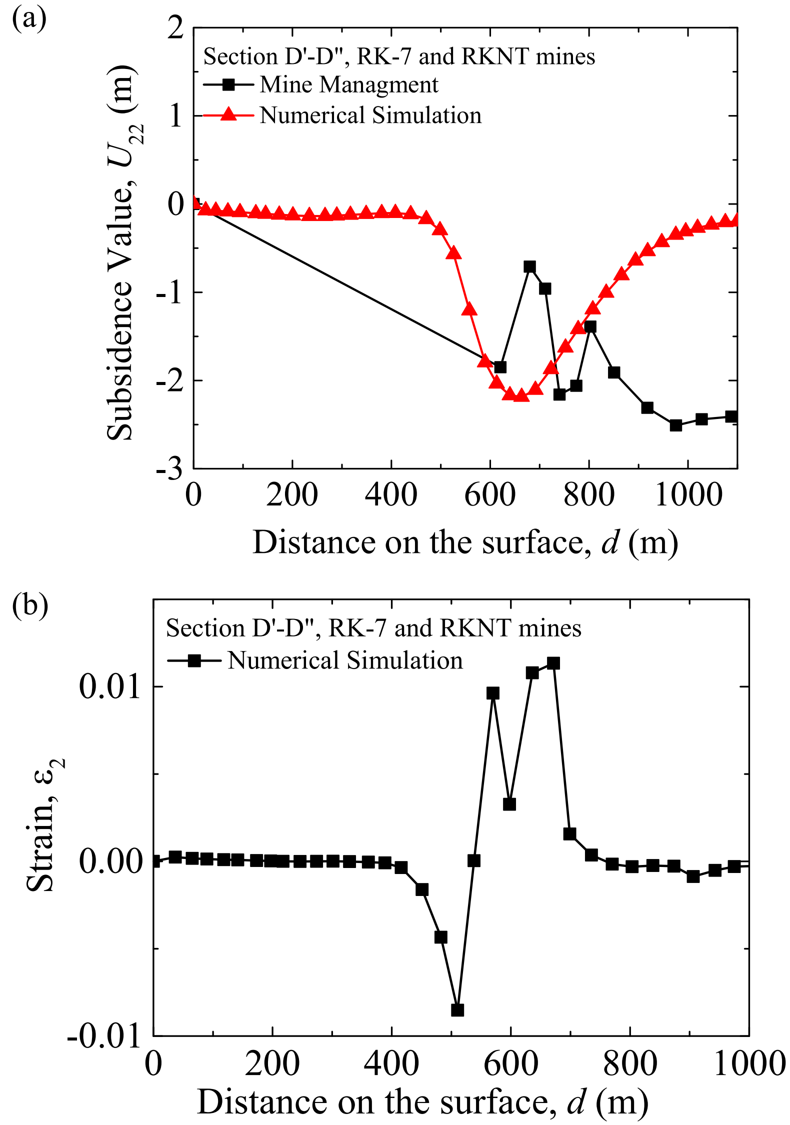


Figure 15: (a) Subsidence profile, (b) Curvature profile on the surface of RK-7 and RKNT mines for Section D'-D".

Figures 13 and 14 show the stress and strain contours obtained from the FE analysis of section D'-D" for subsidence analysis under gravitational load for RK-7 and RKNT only. Similar to previous section analysis, it is noted from the numerical simulation that the maximum subsidence occurred on the surface of RK-7 and RKNT mines and is less than the values measured from subsidence measuring stations installed over the surface of RK-7 and RKNT mines, i.e., 2.18 m from the numerical simulations and 2.51 m from the subsidence measuring stations. The comparative graph of the subsidence from the numerical study and from the subsidence measuring stations as provided by the mine management is shown in Figure 15(a). From the strain contours obtained from numerical simulation and physical data from the measuring stations, the angle of draw and angle of break for RK-7 and RKNT mines are found to be 21.32 degree and 13 degrees, respectively. The curvature and tilt profiles with surface strains generated on the surface are also shown in Figure 15(b) for RK-7 and RKNT mines.

Table 5: Subsidence values generated on the surface of RK-7 and RKNT underground mines in Section D'-D" from numerical simulations.

Mine	Sections	Point taken from surface				
		Maximum Subsidence Value, *d* (m)		Maximum Strain Values, ε (mm/m)	Angle of Draw (°)	Angle of Break (°)
		Measuring Stations	Numerical Simulations			
RK-7 and RKNT	D'-D"	2.51	2.18	8.52	21.32	13

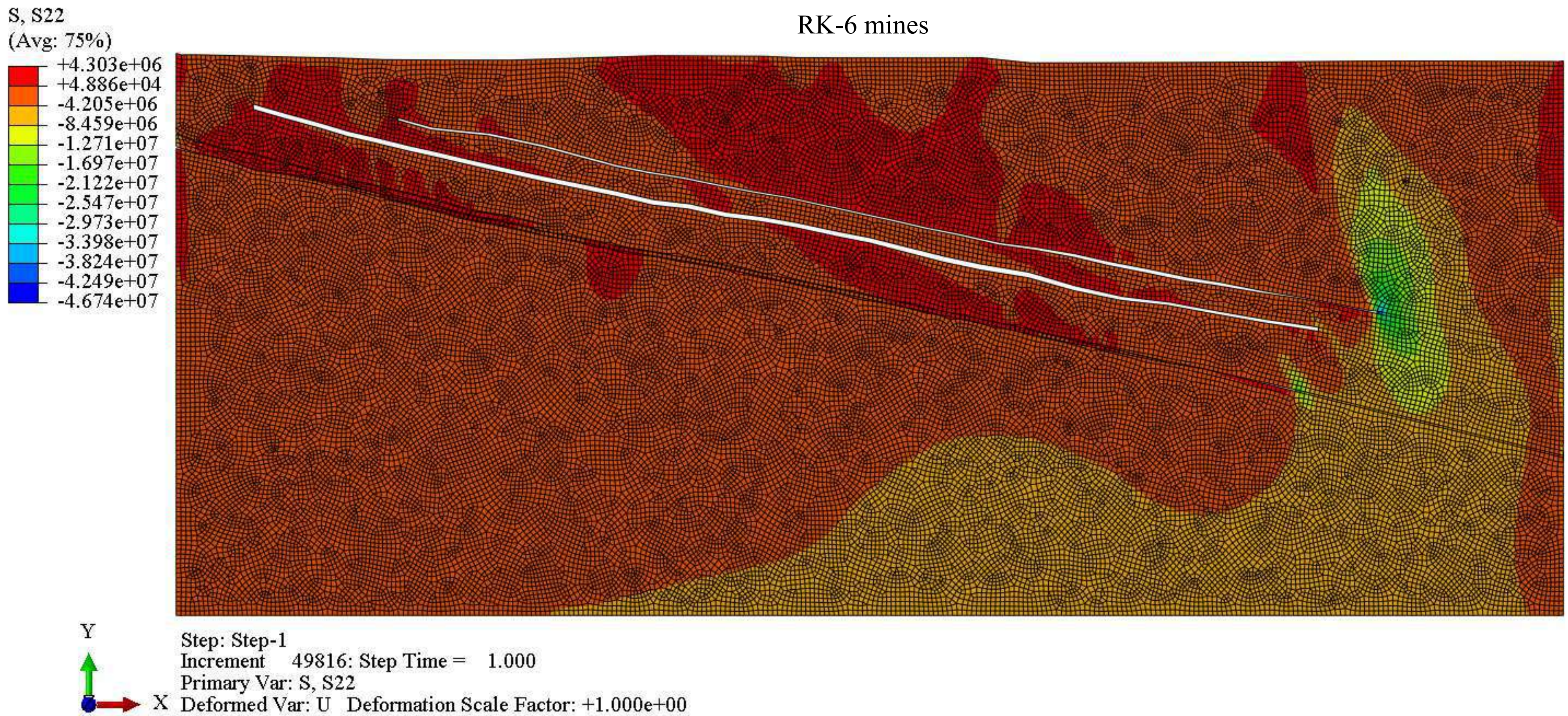


Figure 16: Stress contours for RK-6 mine of section E-E' in y-direction under the action of gravitational load (All values in SI unit, S22 is in Pa).

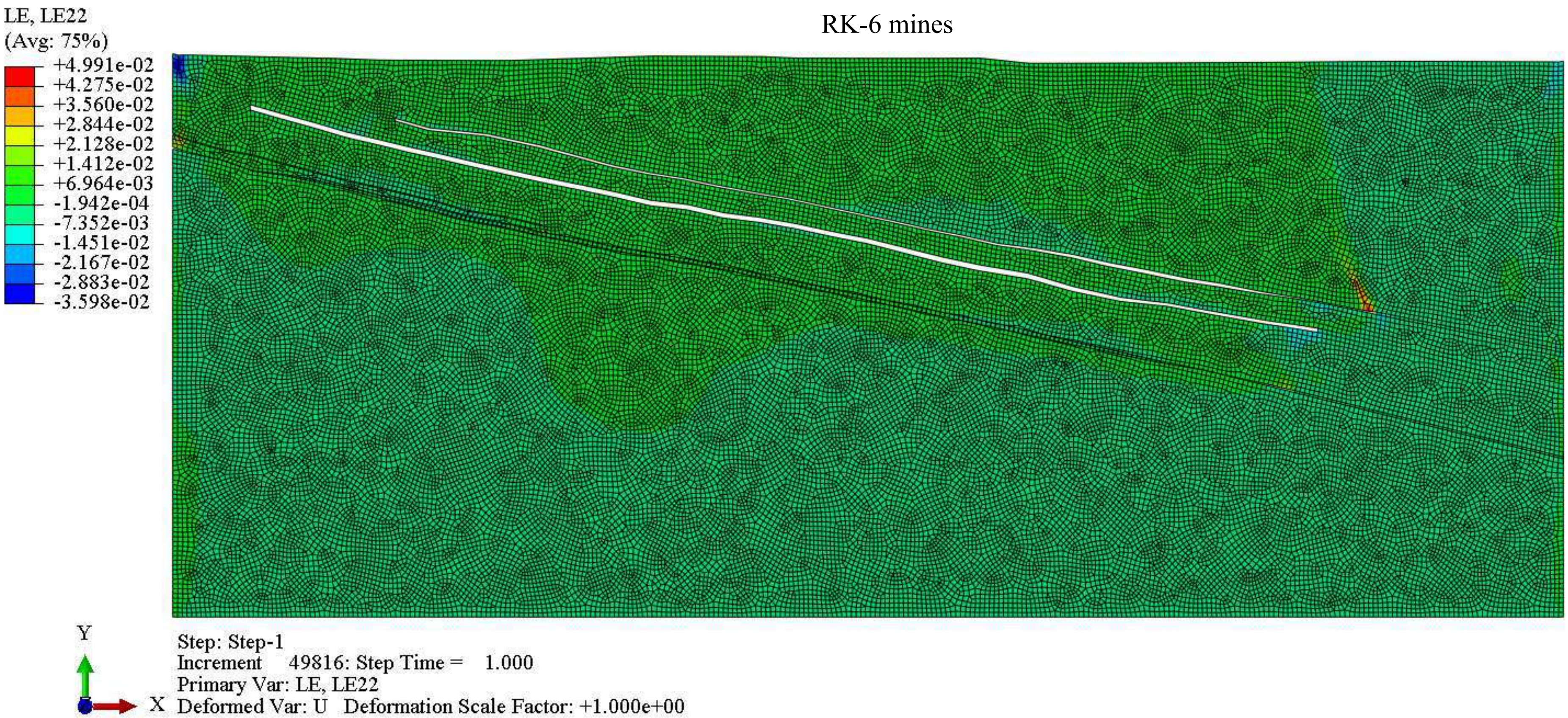
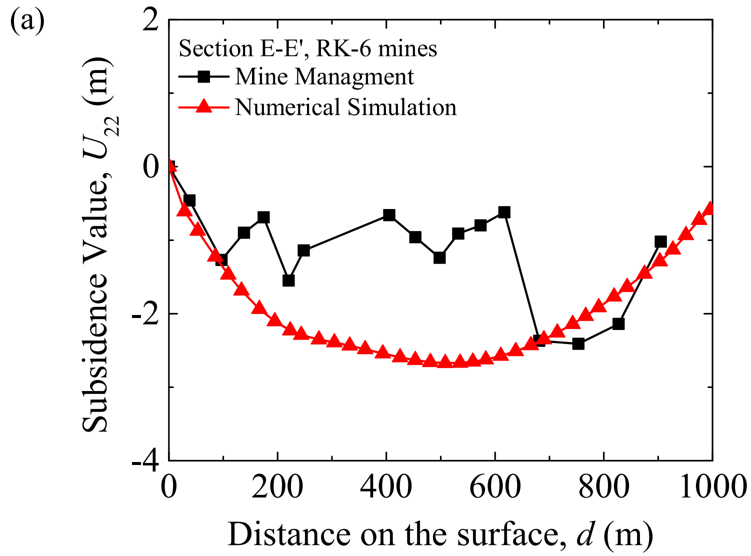


Figure 17: Strain contours for RK-6 mine of section E-E' in y-direction under the action of gravitational load (All values in SI unit, LE22 is in m/m).



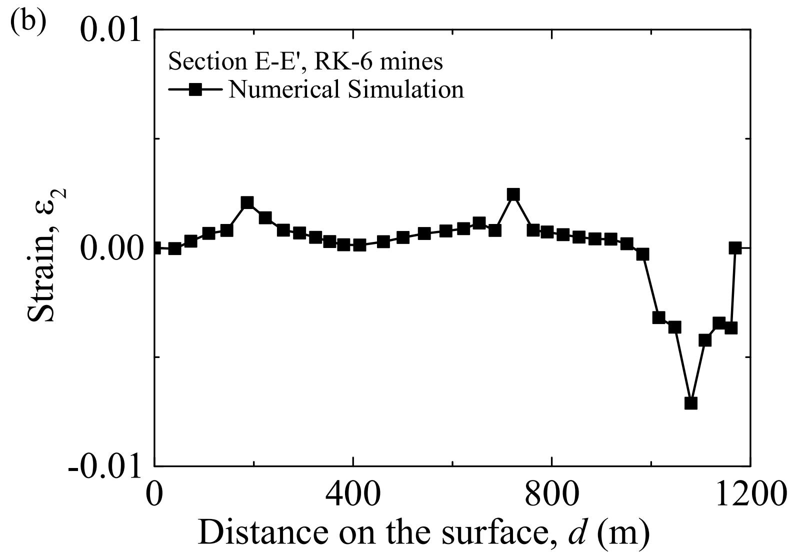


Figure 18: (a) Subsidence profile, (b) Curvature profile on the surface of RK-6 mines for Section E-E’.

Figures 16 and 17 show the stress and strain contours obtained from the FE analysis of section E-E' for subsidence analysis under gravitational load for RK-6 only. Similar to previous section analysis, it is noted from the numerical simulation that the maximum subsidence occurred on the surface of RK-6 mine is almost equal to the values measured from subsidence measuring stations installed over the surface of RK-6 mines, i.e., 2.65 m from the numerical simulations and 2.41 m from the subsidence measuring stations. The comparative graph of the subsidence from the numerical study and from the subsidence measuring stations as provided by the mine management is shown in Figure 18(a). From the strain contours obtained from numerical simulation and physical data from the measuring stations, the angle of draw and angle of break for RK-6 mines are found to be 29.28 degree and 14 degrees, respectively. The curvature and tilt profiles with surface strains generated on the surface are also shown in Figure 18(b) for RK-6 mines.

Table 6: Subsidence values generated on the surface of RK-6 underground mines in Section E-E' from numerical simulations.

Mine	Sections	Point taken from surface				
		Maximum Subsidence Value, *d* (m)		Maximum Strain Values, ε (mm/m)	Angle of Draw (°)	Angle of Break (°)
		Measuring Stations	Numerical Simulations			
RK-6	E-E'	2.41	2.65	7.11	29.28	14

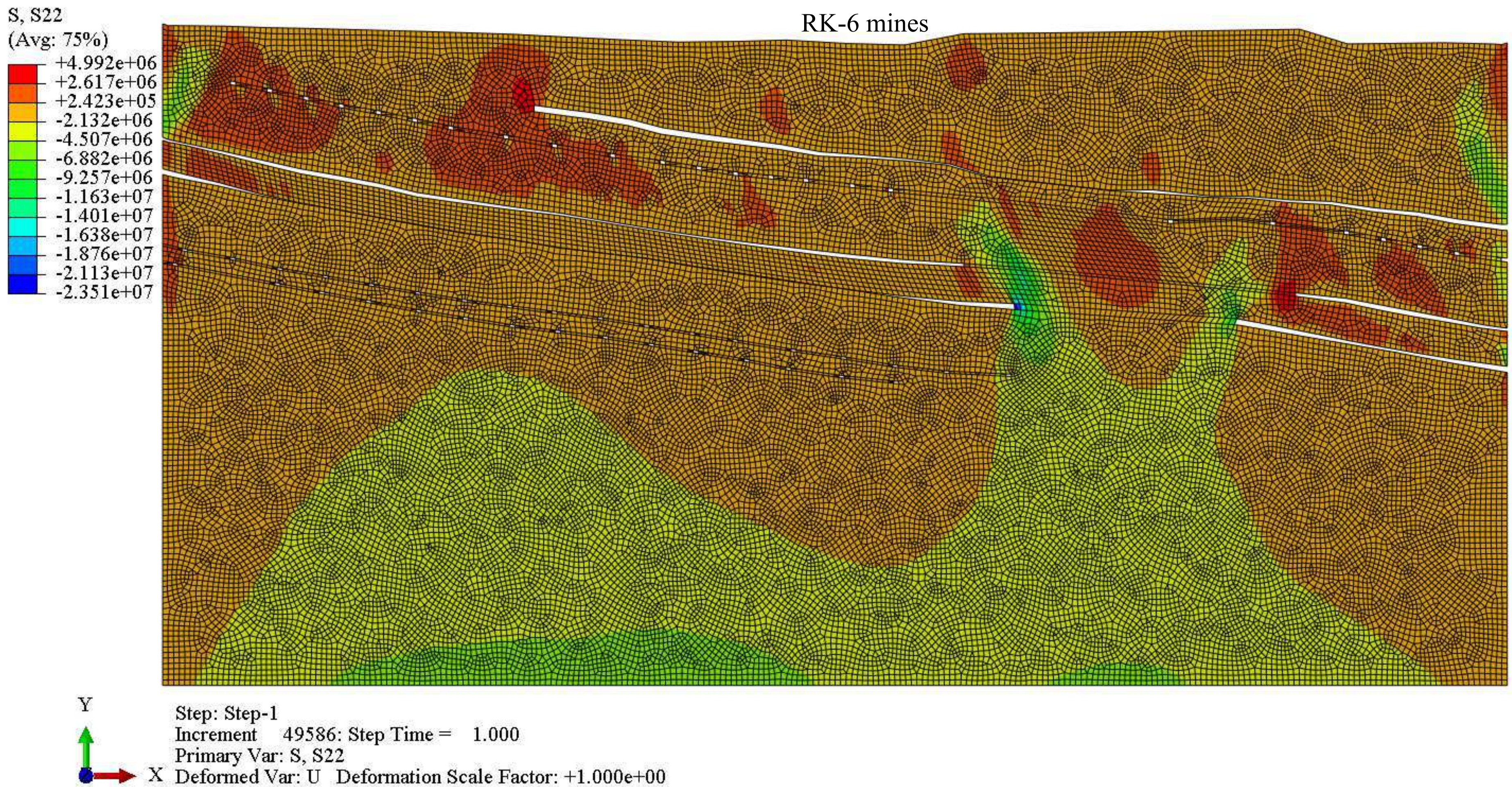


Figure 19: Stress contours for RK-6 mine of section F-F' in y-direction under the action of gravitational load (All values in SI unit, S22 is in Pa).

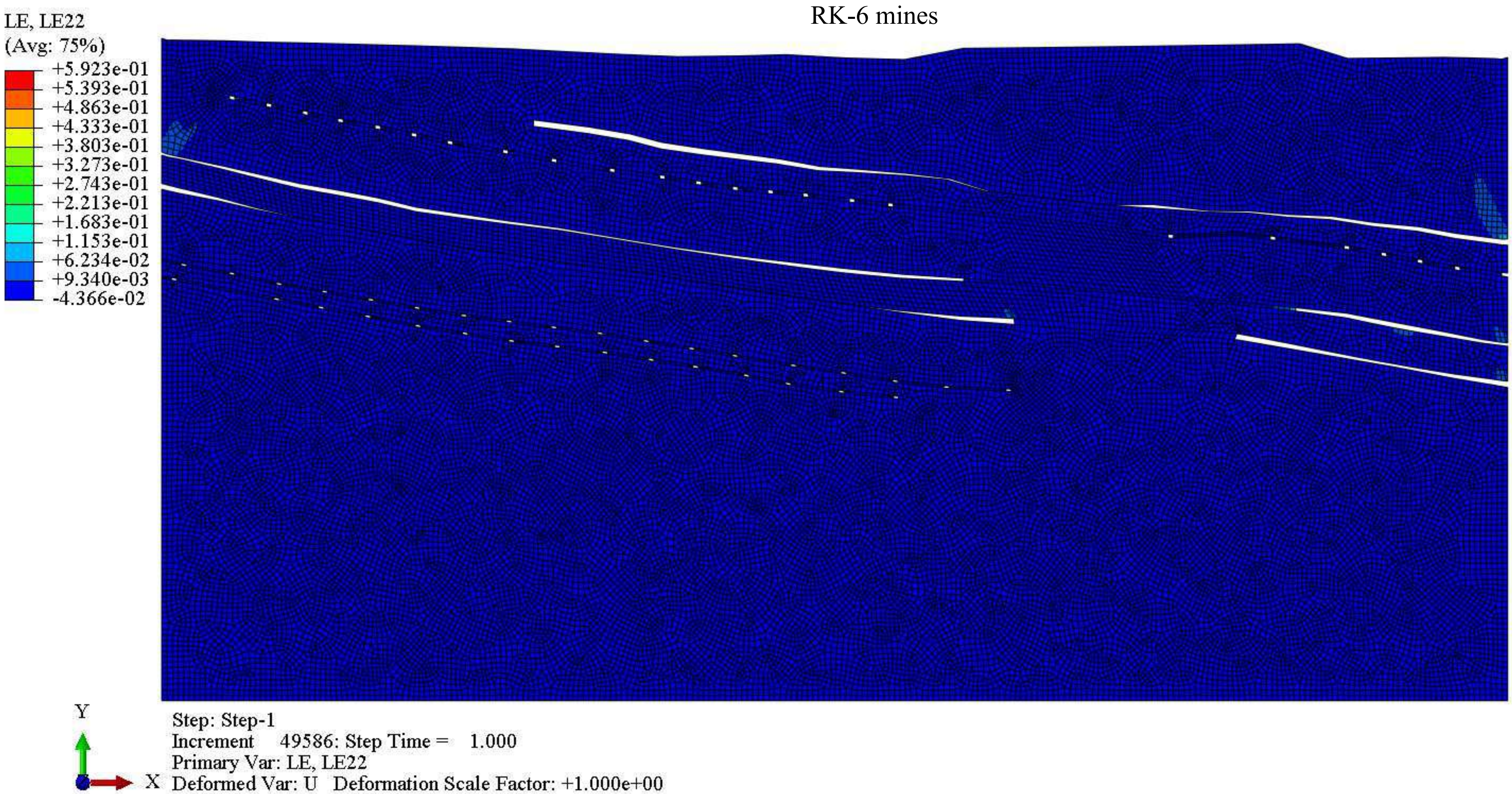


Figure 20: Strain contours for RK-6 mine of section F-F' in y-direction under the action of gravitational load (All values in SI unit, LE22 is in m/m).

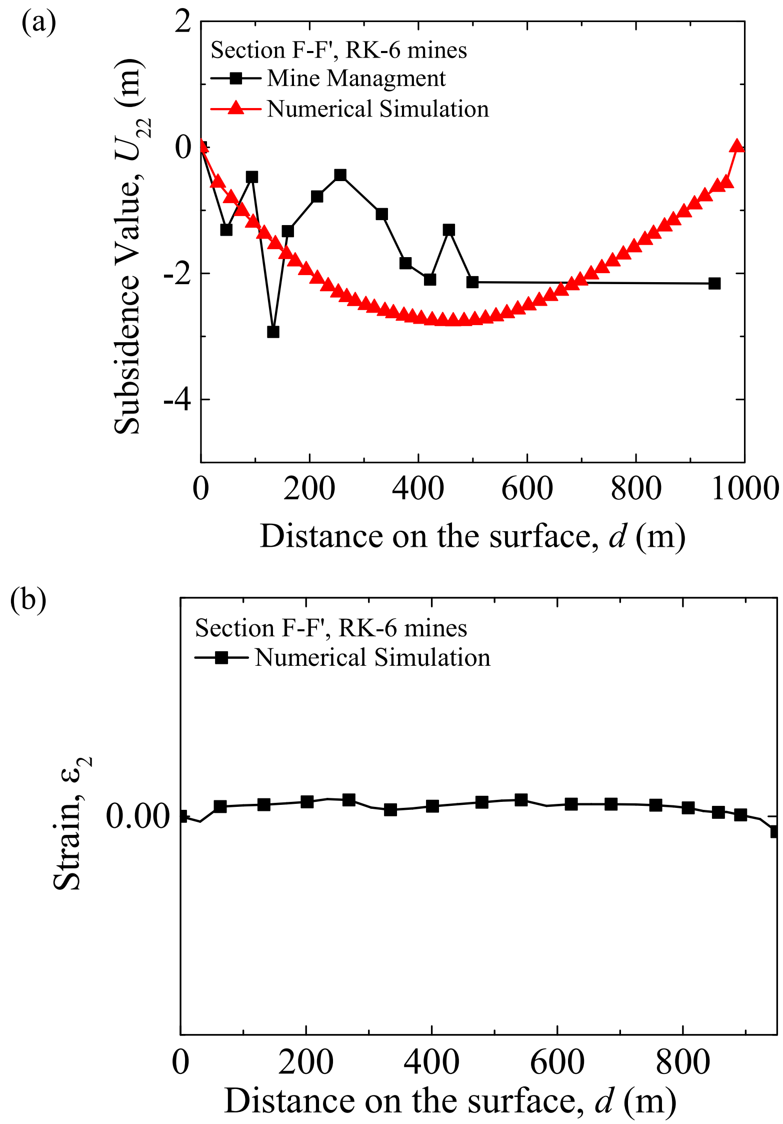


Figure 21: (a) Subsidence profile, (b) Curvature profile on the surface of RK-6 mines for Section F-F'.

Figures 19 and 20 show the stress and strain contours obtained from the FE analysis of section F-F' for subsidence analysis under gravitational load for RK-6 only. Similar to previous section analysis, it is noted from the numerical simulation that the maximum subsidence occurred on the surface of RK-6 mine is almost equal to the values measured from subsidence measuring stations installed over the surface of RK-6 mines, i.e., 2,76 m from the numerical simulations and 2.93 m from the subsidence measuring stations. The comparative graph of the subsidence from the numerical study and from the subsidence measuring stations as provided by the mine management is shown in Figure 21(a). From the strain contours obtained from numerical simulation and physical data from the measuring stations, the angle of draw and angle of break for RK-6 mines are found to be 30.97 degree and 21 degrees, respectively. The curvature and tilt profiles with surface strains generated on the surface are also shown in Figure 10(d) for RK-6 mines.

Table 7: Subsidence values generated on the surface of RK-6 underground mines in Section F-F' from numerical simulations.

Mine	Sections	Point taken from surface				
		Maximum Subsidence Value, *d* (m)		Maximum Strain Values, ε (mm/m)	Angle of Draw (°)	Angle of Break (°)
		Measuring Stations	Numerical Simulations			
RK-6	F-F'	2.93	2.76	0.78	30.97	21

As the results obtained from the numerical simulation is found to be on higher side of the subsidence data measured from subsidence measuring stations, it is therefore suggested to monitoring of the surface strains may be continued by the mine management as is being done now following DGMS Circular number 4 of 1988.

Table 8: Summary of the subsidence values generated on the surface of Ravindrakhani underground mines from numerical simulations.

Mine	Sections	Point taken from surface				
		Maximum Subsidence Value, *d* (m)		Maximum Strain Values, ε (mm/m)	Angle of Draw (°)	Angle of Break (°)
		Measuring Stations*	Numerical Simulations			
RK-7 and RKNT	A-A’	1.83	1.63	5.57	29.62	18
RK-8		-	2.76	9.71	34.92	18.23
RK-7 and RKNT	B-B’	1.77	2.54	9.43	24.64	13.22
RK-6		1.73	2.51	3.35	20.65	10
RK-7 and RKNT	C-C’	1.96	1.36	7.91	29.50	19
RK-7 and RKNT	D’-D”	2.51	2.18	8.52	21.32	13
RK-6	E-E’	2.41	2.65	7.11	29.28	14
RK-6	F-F’	2.93	2.76	0.78	30.97	21

*Data supplied by mine management

The values of various subsidence parameters are listed in Table 8. The subsidence parameters for the Ravindrakhani mines obtained from the numerical analysis of the six sections is found to be in the range of 20-31 degrees and 13-21 degrees for angle of draw and angle of break, respectively.

6. Detailed subsidence monitoring layout plan and design for constructing the subsidence stations over the specified area of 823.19 Ha.

The detailed subsidence monitoring layout plan over the specified forest area is done in accordance with the DGMS Regulations Circular Technical number 4/1988.

The plan must be designed keeping the following points in consideration:

- The lines of observation or test lines for subsidence surveys should be carefully laid out. Whenever possible, the test lines may be laid out in the direction of and at right angles to the line of extraction. The levelling stations should be fixed not more than 6 m apart near the panel barriers and 15/30m apart elsewhere. The stations should be of permanent nature so that they are available for observations even after the completion of depillaring operations.
- The lines of observation should extend beyond the panel upto a distance equal to the depth of the seam. The levelling should, however, commence from stable benchmarks situated well outside the above zone.
- The interval of time between the successive observations would vary depending upon various factors but such observations may be taken, at least once a month when the depillaring operations are in progress and also up to at least one year after the depillaring operations have been completed in the area and at lesser frequencies thereafter. This is to see if any further subsidence is taking place and to ensure that the observation stations will be available for recording movements caused by any future workings.
- Whenever practicable, spot levels should also be taken at the floor of overlying workings and at the roof of workings; underlying within 12m if any, these observations may cover the panel and at least a 30 m fringe all-round.
- Separate subsidence plans and sections may be maintained showing, interalia:
  a. observation points in the test lines
  b. depillared area and/or the area under extraction
  c. geological disturbance(s) if any
  d. extent of extraction (and dates) at the time of (i) first (local) fall (ii) first main fall
  e. extent of surface subsidence (where the overlying seam(s) have been depillared. The line of subsidence for the different seams should be shown in different colours)
  f. method of extraction
  g. a section of the strata overlying the seam under extraction indicating
     i. thickness and nature of overlying strata
     ii. condition of overlying and underlying seam if any: (whether they are depillared, virgin, etc.)
  h. amount of subsidence from time to time
  i. angle of draw and
  j. the point at which maximum tensile and compressive strains were observed (indicate values thereof).

Subsidence plans may be prepared on the same scale at which the statutory plans are maintained. Sections showing total subsidence may be plotted to an exaggerated scale with the surface profile and relative position of the seam(s) and workings plotted to a natural scale.

7. Recommendations and Conclusions

Hence, it is concluded from the physical site inspection and numerical study that there are visible surface strains above the underground Ravindrakhani mines and would affect the forest reserve present in the above-mentioned area to some extent. As the seams in the mine are being depillared leaving caved goafs behind, there will be some amount of subsidence over the ground surface with average values of angle of draw and angle of break as 28.86 degree and 15.80 degrees, respectively as found from the measuring stations and the present numerical simulations. Since the mine is operational and currently the depillaring action is under process, the results obtained from subsidence monitoring stations and numerical simulation concludes that there may be strains on the surface of the mines. However, the strains are within the limit mentioned in the Forests Conversation Act, 1980 and Forest Conservation Rules 2003. It is therefore suggested that the subsidence monitoring of the surface strains may be continued by the mine management as is being done now following DGMS Circular number 4 of 1988.

Moreover, it is clearly mentioned in the Forests Conversation Act, 1980 and Forest Conservation Rules 2003, that the maximum tensile strain of 20 mm per meter and thereby surface cracks of width of about 200-300 mm is to be permitted in forest areas. However, according to the Writ Petition (Civil) No. 202 of 1996, the NPV for the subsidence caused due to mining is NIL for strain values less than 5 mm/m and 10% of the normal rate for 5 mm/m to 10 mm/m strain values. The NPV of 10% of normal rate is to be followed for all mines as the subsidence values lie between 5 mm/m to 10 mm/m in the forest land.

Finally, the IIT Kharagpur team are available to give any additional information required from the present study.

Sunita Mishra

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(Principal Investigator)	(Co-PI, Retired on 30th June 2023)