

# The model of surface subsidence process at subsidence through formation

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The Coalfield of the Western Donbas is located in the central area of Ukraine. Coal seams are extracted in ten mines. Covering seams of a deposit are presented by rocks of Carboniferous period and detrital deposits. Cover depth lies between 120 and 600 meters, stratum inclination 3-5 degrees.

Coal seams are extracted by longwalls. In longwall mining, a panel of coal is typically around 150 to 200 meters wide, 1000 to 2500 meters long and to 1.5 metres thick. It is totally removed by longwall shearing machinery, which moves back and forth across the coalface.

If the width of an extracted panel of coal is small and the rocks above the seam are sufficiently strong, it is possible that the roof will not collapse and no appreciable subsidence will occur at the surface. However, to maximise the utilisation of coal resources and for other economic reasons, wide panels of coal are generally extracted and the roof is unable to support itself in most cases.

As the immediate roof strata, i.e. the rocks immediately above the seam, collapse into the goaf, the rocks above them lose support and sag to fill the void beneath them. The mechanism progresses towards the surface and the affected width increases so that at the surface, an area somewhat larger than the extracted panel of coal undergoes settlement. The majority of the subsidence occurs over the centre of the longwall and tapers off around the perimeter of the longwall. The subsidence is typically less than the thickness of extracted coal. The subsidence of the surface is considerably less than the thickness of coal removed (for Western Donbas extracted thickness of coal seam is 0.9 meters).

The angle at which the subsidence spreads out towards the limit of subsidence at the surface is referred to as the boundary angle.

The boundary angle depends upon the strength of the strata and the depth of cover rocks to the coal seam and typically lies between 60 and 85 degrees from the horizontal, depending on how the limit of subsidence is defined.

In the Coalfields of Western Donbas, if local data is not available, the cut-off-point is taken as a point on the surface defined by an angle of boundary of 65 degrees from the edge of the extraction in rocks of Carbon and 45 degrees in detrital deposits.

The extent of the settlement at the surface is therefore dependent upon the strength and nature of the rocks overlying the coal seam and is a direct function of their capacity to bridge over the voids.

The subsidence at the surface does not occur suddenly but develops progressively as the coal is extracted within the area of influence of the extracted panel. When extraction of coal from a panel is commenced, there is no immediate surface subsidence, but as the coal within the panel is extracted and the resulting void increases in size, subsidence develops gradually above the goaf area.

As mining continues, a point is reached within the panel where a maximum value of subsidence occurs and despite further mining beyond this point, within the panel, this level of subsidence is not increased.

The development of subsidence at any point on the surface of the ground is seemed to be a very complex mechanism and the cumulative effect of a number of separate movements.

Subsidence, tilt, horizontal displacement, curvature and strain are the subsidence parameters normally used to define the extent of the surface movements that will occur as mining proceeds and generally form the basis for the assessment of the subsidence impacts on surface infrastructure.

These parameters are illustrated in Fig. 1 which shows a typical subsidence profile drawn to an exaggerated vertical scale.

Subsidence usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements are usually greater than the vertical subsidence, where the subsidence is small.

Tilt is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. The maximum tilt, or the steepest portion of the subsidence profile, occurs at the point of inflection in the subsidence trough, where the subsidence is roughly equal to one half of the maximum subsidence.

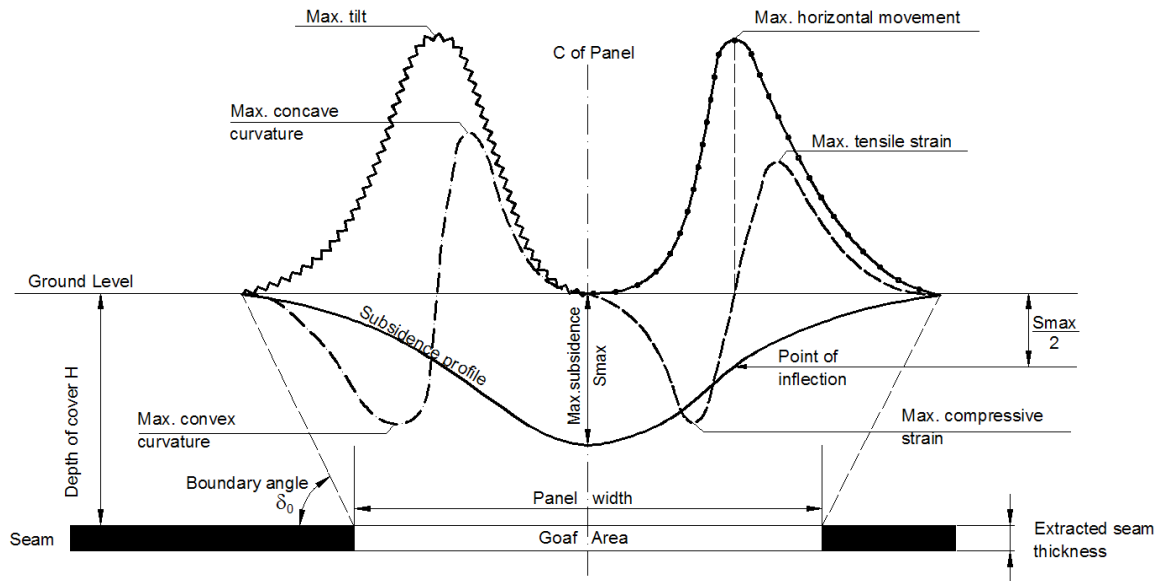


Fig. 1 Profiles of typical subsidence parameter above a single longwall panel

The horizontal component of subsidence, or horizontal displacement, is greatest at the point of maximum tilt and declines to zero at the limit of subsidence and at the point of maximum subsidence.

Curvature is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections.

Strain is caused by bending and differential horizontal movements in the strata. Measured strain is determined from monitored survey data by calculating the horizontal change in length of a section of a subsidence profile and dividing this by the initial horizontal length of that section. If the section has been extended, the ground is in tension and the change in length and the resulting strain are positive. If the section has been shortened, the ground is in compression and the change in length and the resulting strain are negative.

In the majority of cases the movement of strata is extended to the surface. Thus, buildings and structures in the zone above mine workings are subject to subsidence, and sometimes to destruction.

The most significant impacts on surface infrastructure are experienced during the development of the subsidence trough, when maximum ground movements normally occur. As the subsidence wave approaches a point on the surface, the ground starts to settle, is displaced horizontally towards the mined void and is subjected to tensile strains, which build from zero to a maximum over the length of convex or hogging curvature.

If a structure is located on the perimeter of the subsidence trough, it will only be slightly affected. It will suffer little settlement and will have little residual tilt or strain. A structure or surface feature on the side of the trough between the tension and compression zones will experience some subsidence, and will be left with residual horizontal displacement and tilt. But it will be subjected to lower curvatures and strains. Structures or surface features located at the positions of maximum curvature and strain would generally suffer the greatest impact.

Under specific natural conditions the movement of strata may cause the deviation of shafts, drainage of water bodies, destruction of pipelines, caving of the opencast, etc. Therefore, the strata movement may impair substantially the national economy, and sometimes even lead to human accidents. This imposes on mining engineers the task of studying strata movement, to protect buildings and structures against its effects.

The surface subsidence over the panel is a long process. Three stages of development can be allocated in this process: a formation stage, a stage of synchronous displacement and a decrease stage. There are three areas in subsidence trough which correspond to development stages of subsidence process distinguish (Fig. 2).

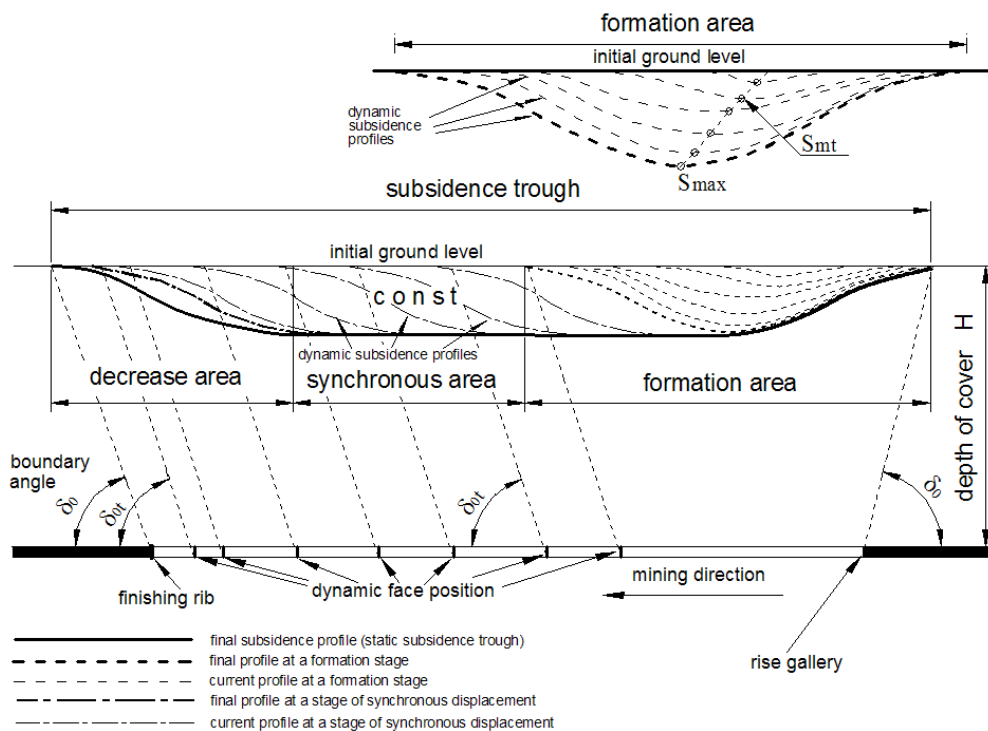


Fig. 2 The scheme of a surface subsidence in the process of longwall working out

The formation area is dynamic subsidence trough from the moment of the beginning of a surface subsidence process till the moment when the maximum subsidence reaches a limit. The maximum subsidence in the trough increases as excavation width increases. The profile of trough constantly changes.

As mining continues, a point is reached within the panel where a maximum value of subsidence occurs. Despite further mining beyond this point, within the panel, this level of subsidence is not increased.

The synchronous area is characterized by constancy of geometrical parameters and character of subsidence distribution over stope which moves.

The decrease stage of subsidence process shows a surface subsidence from the moment, when the extraction has stopped, till expiration of subsidence process

As a rule, researches of surface subsidence in a time are carried out in the synchronous area of subsidence. It limits the usage of researches results for definition of laws of subsidence process. Subsidence trough development at a formation stage remains investigated insufficiently. Not numerous publications describe some laws of development of a surface subsidence and horizontal displacement to an initial stage of a mining

The department of mine surveying of NMU carries out research of surface subsidence on mines of the Western Donbass. On the basis of these researches the technique of time-space modelling of surface subsidence is developed. This technique allows to create graphic model of subsidence process over moving stope at stage of a subsidence trough formation.

Model of surface subsidence process is shown on an example of results of measurements which are executed at observation station № 9. This station is located above longwalls 605 and 607 of a coal seam c'6 (Fig. 3).

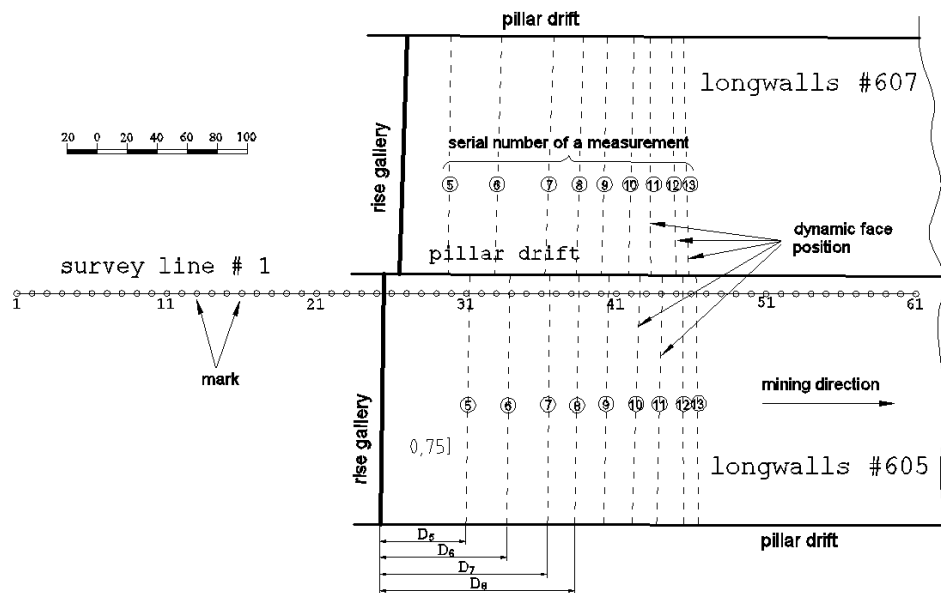


Fig. 3 The plan of observation station number 9 and graphics of surface subsidence over 605 and 07 lavas

The face advance rate varied between 2 and 3 m/day and the mining depth between 200 and 250 m (the depth of rise gallery of 250 m). Stratum inclination of 4 degrees. Above a coal seam the bedrocks and weak detrital deposits are present, detrital deposits thickness is 80 m. The ratio of thickness of detrital deposits and Carboniferous strata is 0,32. The effective thickness of seam of 0,75 m. The maximum surface subsidence after the termination of strata displacement process is 680 mm.

The leveling of marks was carried out at observation line. By results of measurements the spot height of marks are calculated. The first measurement is executed prior to the beginning of working of longwalls. In the process of working 19 series of measurements are executed. These measurements were carried out within 5 months from the working beginning. Each observation reflects a surface subsidence which corresponds to the size of goaf (width of extraction)  $D$  for survey date. The initial profile and dynamic profiles of subsidence are constructed according to these data (Fig. 4).

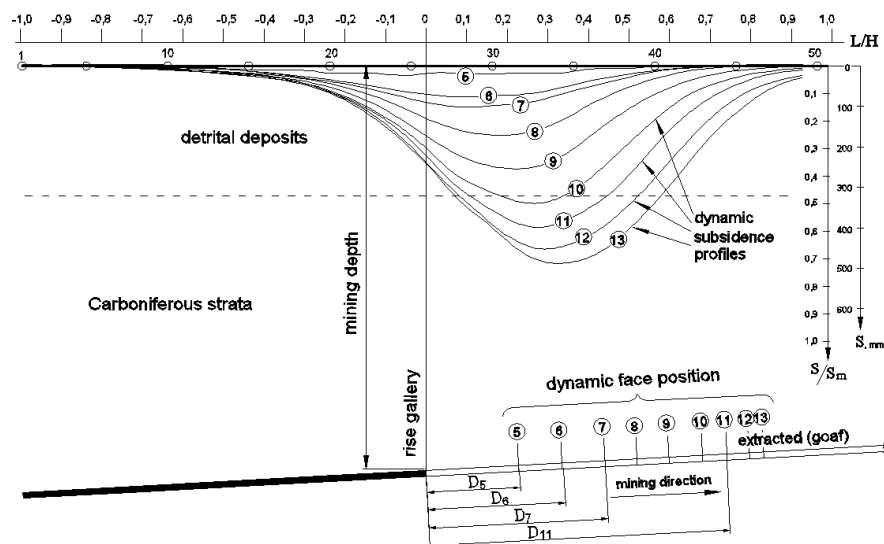


Fig. 4 The initial profile and dynamic profiles of subsidence

The creation of time-space model of surface subsidence process begins with reduction of all data to a unit type. For this purpose linear parameters (current width of extraction  $D$ , distances between supervision survey marks on surface  $L$ ) are presented in the form of relation  $D/H$  and  $L/H$ . Marks subsidence for survey date are presented by the relation.

In our model the basic co-ordinate system is presented by an ordinates axis, on which transfer the distance to longwall face for survey date ( $D/H$ ). The abscisses axis ( $L/H$ ) corresponds to a survey line direction. On these axes the point "0" corresponds to rise gallery locating.

In the basic co-ordinates system an additional local co-ordinates systems are located. Their number is equal to quantity of measurement series. Each local co-ordinates system settle down on ordinate, which corresponds to distance of coal face for survey date. The dynamic subsidence profile for survey date is created in local systems (Fig. 5).

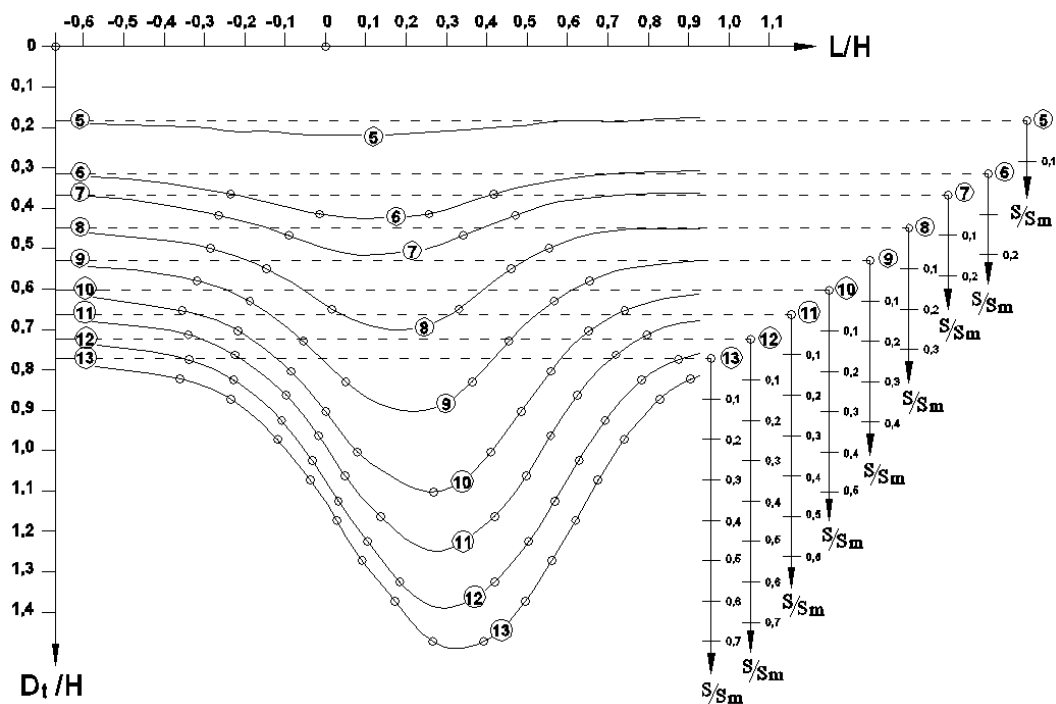


Fig. 5. Graphics of surface subsidence, placed in the local coordinate systems

The size of distance to longwall face from rise gallery indirectly corresponds to time, as it is a product of extraction speed and time from the extraction beginning. Thus, all dynamic profiles as a whole show a subsidence development in time.

On each local dynamic profile the points, in which subsidence sizes are multiple (0,1), are determined. Through points, which have identical values of subsidence on all local profiles, smooth curves draw. The physical sense of these curves consists that they characterized time of formation and a location of subsidence, whose value is multiple (0,1).

Curves which connect points of identical subsidence are isolines. Proceeding from physical sense, these isolines are named by "chronoisosubsidence". The subsidence model is named by a "chronoisolinear". The chronoisolinear subsidence model allows defining a surface subsidence value for any moment of time  $t$ . For this purpose a width of exploitation ( $Dt$ ) for demanded date is necessary.

On the model drawing (Fig. 6) a horizontal line with ordinate  $Dt/H$  is showed. Find points are crossing with chronisolines. From these points the segments are drawn. Their length is equal to an isoline value that is subsidence.

The ends of segments mark out a subsidence trough profile at the time  $t$ .

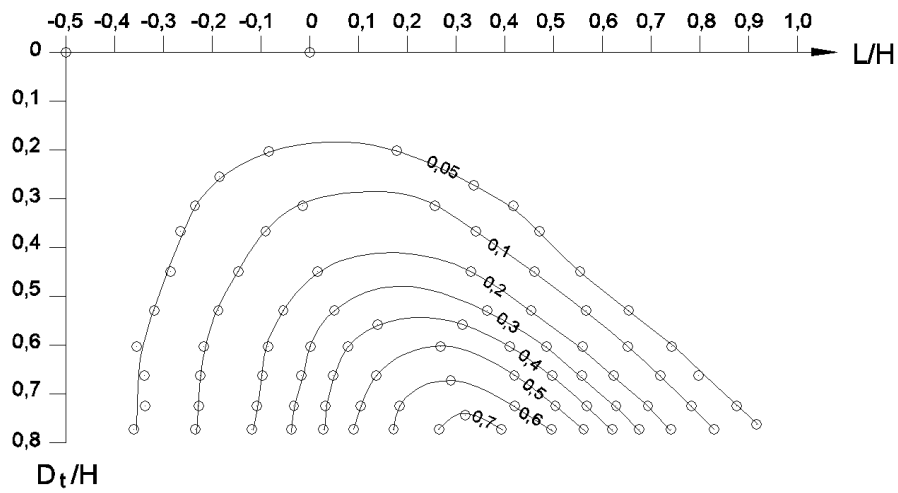


Fig. 6 The "chronoisolinear" model of subsidence

Thus, the majority of known subsidence models actually are not dynamic. They either static, or quasistatic, or quasidynamic. The proposed chronoisolinear model of subsidence is really dynamic. This model allows fixing continuously values of subsidence above face which moves. It is implemented by use of an isolines method, which are continuous by definition.

The model presented above, "works" correctly in specific conditions. These are conditions for 605 and 607 longwalls. For creation of more universal model it is necessary to execute extensive surveying researches within a deposit or a large part of a deposit.