Subsidence
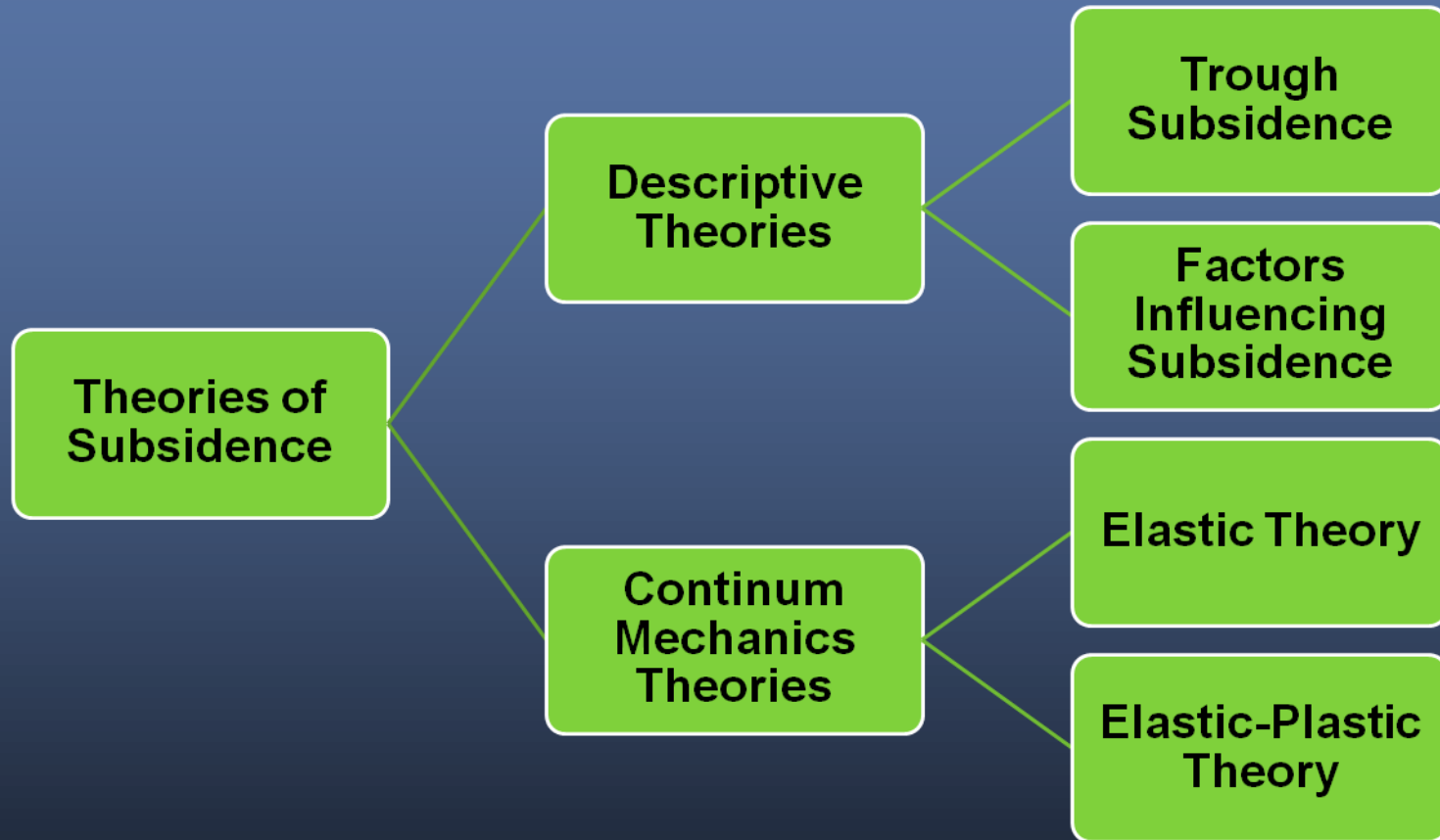
Contents

- Theories of subsidence
- Subsidence measurement techniques
- Damages due to subsidence
- Methods of preventing damages

Classification of Theories of Subsidence

Descriptive Theories

- Observation of surfaces above the excavated U/G openings form the basis of deductions w.r.t. ground movements between the surfaces & U/G openings

- Wider applicability than continum mechanics theories

- Bulk of current understanding about subsidence characteristics derives from these theories

Continum Mechanics Theories

- Used to derive information on stresses & strains
- Difficult to apply because of complex variation of geological structures from area to area, the exact boundary conditions & material properties

Trough Subsidence

- This type of subsidence is usually associated with the extraction of thin, horizontal or flat-dipping ore bodies overlain by weak, non-brittle sedimentary strata

- Surfaces directly above excavated openings usually subside in a trough

- The area of which extends beyond the limits of the excavated underground opening

- Trough subsidence is symmetrical about mining geometry with maximum subsidence at the midspan of opening

- Magnitude of subsidence gradually reduces outwards and away from the centre and vanishes

Trough Subsidence Over a Longwall Extraction
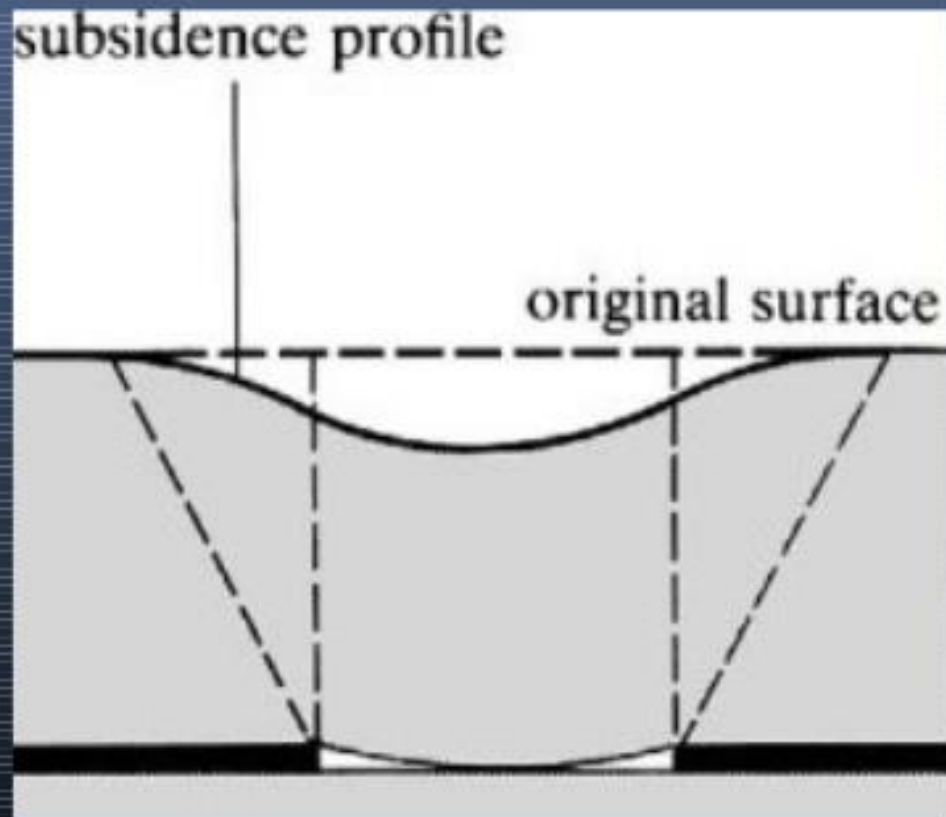
Source: B.H.G. Brady, E.T. Brown-Rock Mechanics

Factors Influencing Subsidence

- Angle of draw
- Seam thickness
- Width & depth of opening
- Type of supports
- Seam inclination
- Time

Angle of Draw

- It is the angle between the vertical & the line joining edge of excavation with the point at the surface where subsidence diminishes to zero

- It defines the limit of subsidence w.r.t. to a particular U/G opening and is sometimes called limit angle

- It ranges from 8^0-45^0 depending on the coal field (Coal Mine Ground Control, Syd S. Peng)

- It depends on depth, seam thickness, & local geology, especially major faults or fracture planes or the location of self-supporting strata above the coal seam

Seam Thickness

- Affects the magnitude of surface subsidence

- If all other factors are same, then thicker the seam, the larger is the surface subsidence, because a larger void is left to be filled

- The max. possible surface subsidence is $S_{max} = ma$, where, m is seam thickness & a is subsidence factor, which ranges from 0.1-0.9 depending upon coal field, method of packing & also seam depth in few cases (Coal Mining Ground Control, Syd S. Peng)

Width & Depth of Opening

- Width & depth of an U/G opening together determine the critical area or area of influence

- If lines inclined at an angle equal to angle of draw are drawn from a point on the surface above an U/G excavation and if they intersect the coal seam at two points then the distance between these two points is known as critical width

- As the depth increases critical width also increases

- For a coal seam at a fixed depth, if an U/G opening is as wide as the critical width w.r.t. a surface point, then max. possible subsidence occurs at this point

- If the opening is wider than the critical width, an area in the midspan will experience the max. possible subsidence. The width of the opening is then a supercritical width

- If the opening is narrower than critical width, the max. subsidence occurs at the midspan but is less than the max. possible subsidence for the seam. The width of the opening is then called sub-critical width

- An opening of a particular width is a supercritical width at a shallow depth but becomes critical and then sub-critical at greater depths. Therefore, depth & width both must be specified for determining amount of subsidence

Type of Supports

- Amount of convergence of U/G openings depends on type of supports used, which in turn determines the amount of roof materials to be caved or indirectly the magnitude of subsidence

Seam Inclination

- For inclined seams, the surface subsidence trough is displaced toward the deeper edge of the opening and, depending on the inclination, may be located outside the dip edge of opening

Source: http://bellevuewa.gov/
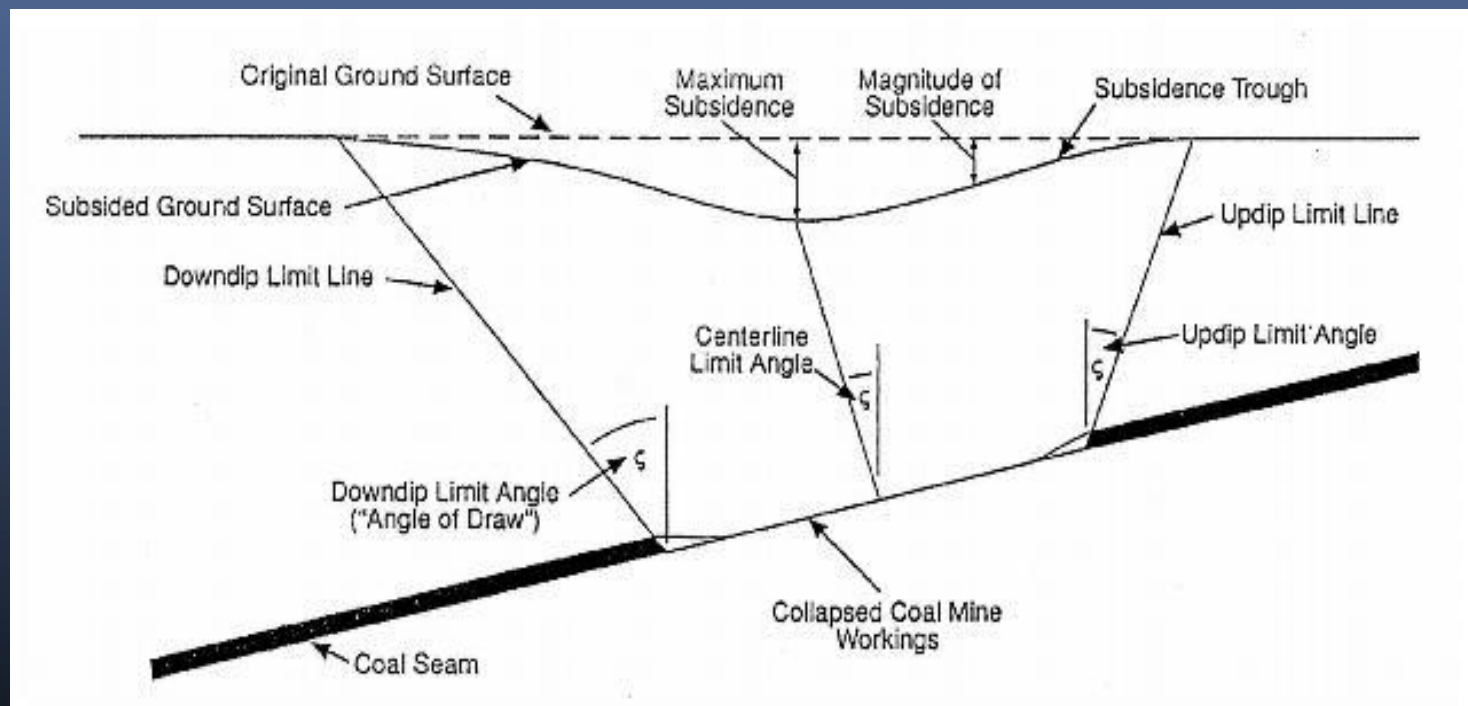
- Subsidence is max. at the point normal to the center of the opening, rather than directly over the center of the opening as in case of horizontal seams

- Angle of draw is no longer constant, but depends on the dip angle of the seam, being smallest at the rise edge of the opening and increases toward the dip edge

Time

- Both instantaneous & time dependent subsidence are associated with U/G excavations

- Time-dependent portion is much less than the instantaneous one. It is also known as residual subsidence

- Residual subsidence may start after the active (instantaneous) subsidence is completed or it may occur simultaneously with instantaneous subsidence

- Amount of residual subsidence is proportional to rate of subsidence of surface points

- Residual subsidence can amount to 9% of total subsidence if face is stopped within the critical width of the surface point & reduces to 2-3% if the face has passed the critical width (U.K. National Coal Board)

- Residual subsidence or the duration of surface subsidence also depends on strata conditions, depth of extraction, kinds of packing & it may range from several days to several years

- Duration is longer for thick-bedded or stronger overburden, for greater depths & for complete caving

- For a small extraction area of a relatively mobile O/B mined in a very short time, the rate of subsidence is proportional to the difference between the final subsidence & instantaneous subsidence

Elastic Theory

- It was given by D.S. Berry in 1964
- Elastic ground movement for three kinds of U/G excavation closure development were analyzed

  1) Non-closure (Floor & roof never met)

  2) Partial closure

  3) Complete closure

- Excavations were treated as displacement discontinuities by using a complex potential method for partial closure
- Results were then extended to non-closure & complete closure as limits
- It was found that surface subsidence calculated for isotropic material was smaller than actual measurements
- Therefore, theory for transversely isotropic ground was developed in two dimensions

Elastic-Plastic Theory

- This was given by Dahl & Choi who found that mine subsidence is essentially time independent & that measured surface strains frequently exceed the elastic limit

- Therefore, they suggested a model which behaves in an elastic-elastoplastic manner

- This model uses three-dimensional finite element method, to reproduce subsidence profiles from the subsidence survey

Subsidence Measurement Techniques

- Measurement of surface movement

  - Establishing surveying stations

  - Horizontal movement

  - Vertical movement

  - Slope

- Measurement of subsurface strata movement

  - U/G borehole technique

  - Surface borehole technique

    (Wireline, TDR, Mechanical grouting method)

Measurement of Surface Movement

- Involves the determination of vertical & horizontal movement from which subsidence, displacement, slope, & curvature of subsided ground surface can be calculated

- All the measurements are geometrical

- First step in measuring surface movement is to establish surveying stations over the extracted area and measure the direction & amount of movement of these stations

Establishing Surveying Stations

- Generally, steel rods driven 2 to 3 ft into the ground are sufficient to serve as surveying stations provided no frozen heaving of ground is expected in the area during subsidence measurements period

- Where frozen heaving occurs it is suggested to drill a 1-ft dia hole, 4 to 5 ft deep, which is then filled with concrete, and then steel rods or screws are set in the concrete

- Subsidence surveying stations should be established along lines parallel & perpendicular to expected excavation area

- Stations are lined up far beyond the edge of the panel

- Bay length between stations should not exceed h/20, where is depth of coal seam below the surface

- Observation points are stations for setting up surveying instruments

- Reference points are permanent stations established in areas where no subsidence is expected during the subsidence survey periods

Horizontal Movement

- The objective of measuring horizontal movement is to calculate surface horizontal strain

- Strain can be determined by change in length over the original length between two neighboring stations

- It can also be determined by determining the exact locations of stations between each succeding survey

- Distance between stations can be measured by tapes, extensometers & electronic distance meters

- Angles are measured with a transit or a theodolite with a sensitivity on the order of ½ sec

- Horizontal strain measured by determining change in locations between neighboring stations can be obtained by intersection method

Vertical Movement

- It can be measured by leveling methods with a theodolite (transit) or a precision level

- When a theodolite or transit is used, angle of slope is measured in a vertical plane from the horizontal plane to the height of surveying station

- Vertical distances from horizontal plane are then added up for each succeeding survey to obtain total subsidence

- When a level is used either differential or profile leveling technique may be employed

Slope

- Slope can be calculated from the subsidence profile or measured by the tiltmeter

- Tiltmeter used for slope measurement is an inclinometer placed on a set of points permanently attached to a surveying station

- Three setting points are used spaced at a radial angle of 120^0

- The change in micrometer screw reading between each successive reading divided by the distance between the legs is the slope

- Slope for each of the three support legs can then be used to determine the direction & magnitude of the maximum slope or tilt

Measurement of Subsurface Strata Movement

- Mainly consists of monitoring strata separation as a function of face location

- Can be done by either underground or surface boreholes

- U/G boreholes are usually drilled in the roof, then roof sag measurements devices are installed for monitoring strata

- With the surface borehole technique, NX-sized boreholes are drilled from the surface all the way down to the coal seam to be mined

- Movement of strata at different horizons above the seam is then monitored from surface as a function of face location using any of the following methods

Wireline Method

- This technique makes use of electronic logging devices commonly used in oil fields
- A bullet perforator is lowered into the well, positioned at the desired level & fired into the wall of the well by means of a surface control
- A small amount of radioactive material is inserted in the bullet, so when it is shot into the strata surrounding the borehole & remains there strata movement can be followed
- Bullets are shot into various strata along the borehole, and their positions are identified with high peaks of intensity in a radioactive log
- The change in a bullet's position indicates the amount & direction of movement of stratum in which bullet is inserted

TDR Method

- TDR or Time Domain Reflectometry, works on the same principle as radar

- A good cable is grouted in the borehole all the way down to the coal seam

- Caving or separation of the roof strata create some sort of faults in the cable

- An ultrafast rise time voltage step is sent down the cable, which is reflected by the fault

- A sampler picks it up & superimposes on incoming signal resulting in a step-up or down which can be seen on CRT

- The time delay between the initial signal & the arrival multiplied by the travel velocity indicates the distance where fault occurs

Mechanical Grouting Method

- A cubic weight hung on a pulley with a counter-weight on the surface is lowered into the borehole to a specific position and grouted with cement

- Movement of weight or the stratum to which it is anchored is monitored by measuring the movement of counter-weight on surface

- A max. of nine anchors can be installed in a NX-hole at different horizons to monitor any differential movement

Damages Due to Subsidence

Ground disturbance in the subsidence trough can be-

- Continuous Ground Disturbance
  - Vertical subsidence & slope
  - Horizontal displacement & strain
  - Curvature

- Discontinuous Ground Disturbance
  - Fissures or cracks
  - Steps
  - Cave-in pits

Vertical Subsidence & Slope

- Vertical subsidence does not cause any damage to structures if it is uniformly distributed, as it is at the center of trough over a supercritical excavation

- The only danger of subsidence troughs like this is the possibility of flooding in low-lying areas

- Differential settlement between neighboring points in along the surface of subsidence trough will form a slope & induce tilting

- This occurs in subsidence troughs caused by subcritical excavations & around the edges of those induced by critical and supercritical excavations

- Differential settlement may disrupt drainage systems, the flow of creeks, gravity flow of liquids in pipelines, grade of higheways or railroad beds

- They may also induce tilting of tall buildings, towers & chimneys and cause instability

Horizontal Displacement & Strain

- Uniform horizontal strain seldom causes direct damage to surface structures

- Differential displacement induces compressive or tensile strains along the surface of subsidence trough

- Strains cause distortion, cracking & failure of buildings, pipelines, highways, bridges, reservoir etc.

- Tensile strain occur in the convex portion of the surface of trough, causing cracks first to develop in the lower portion of the structure & at weak points such as windows or door openings

- Compressive strain occurs in the concave portion of trough & causes squeezing or buckling of foundation slabs, brickworks, rafts etc.

Curvature

- Curvature is the rate of change of slope usually expressed by radius of curvature

- It induces two types of structural damages, first is distortion of the structure due to shear strain

- Second is flexural bending of structures such as long, load bearing walls

Discontinuous Ground Disturbances

- Fissures or Cracks

  - These are open cracks ranging from a few inches to several feet wide

- Steps

  - If planes of weakness are oriented favorably,   ground will slide along these planes and form steps on the surface

  - Steps also range from a few inches to few feet in width

- Cave-in Pits

  - These result from collapsing of the ground and may be as large as several feet wide & deep

Methods of Preventing Damages

- Structural protection
- U/G controlled mining
  - Safety pillars
  - Partial extraction
  - Harmonic extraction
  - Rapid mining
  - Stowing

Safety Pillars

- Safety pillars are the solid coal pillars left untouched to protect surface structures located directly above

- Their size can be determined by the horizontal distance from a surface structure at which the advancing face must stop so that total strain at the site of the surface structure is less than allowable values

- The distance at which advancing face must be stop from structure & thus the size of pillar is a function of seam depth

Partial Extraction

- Surface structure can be protected by partial extraction, using the bord-and-pillar, or panel-and-pillar method

- In this method some pillars are left unmined in the area below the structure

- This area where pillars are left unmined is obtained by the projection of area around the structure on the surface outward & downward towards the seam

Harmonic Extraction

- In this method mining is done in such a manner that strain induced at the site of the structure is minimized due to cancellation of tensile & compressive strains

- Mining is done keeping the faces staggered such that the structure to be protected is located on the common edge of two adjacent panels

- Constant lagging of approximately 1/4th of critical width should be maintained between the panels

- Compressive strain generated by panel face ahead is compensated to some extent by tensile strain from lagging panel face

Rapid Mining

- The max. tensile strain E_t travelling with an advancing face is generally less than the final obtainable max. tensile strain E_{max} and faster the mining, the less E_t is

- Furthermore, the max. compressive strain accompanied with the travelling face is always less than the corresponding max. tensile strain E_t

- Therefore, there exits a minimum rate of mining characteristic of each coal field that will induce max. tensile strain traveling less than the allowable one

Stowing

- Since the amount of subsidence is proportional to the excavated seam height, it can be reduced by stowing of various kinds

- More compacted stowing allows smaller subsidence

- Stowing procedures that permit stowing to be performed immediately after mining induce smaller subsidence than if stowing has to be done long after mining