Review of mechanisms resulting in observed upsidence and closure movements

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Summary

Descriptions of natural valley bulging movements as well as mining induced valley related upsidence and closure movements have been well documented by various authors. It is clear from this research that there are numerous factors which affect these movements and it is likely that the movements comprise a number of mechanisms.

Several models have been forwarded to describe valley related movements resulting from longwall mining. A review of some of these models is presented in this paper. This review indicates that several mechanisms may be in operation at any given site depending on the actual conditions at that site.

An empirical method to predict these movements was developed as part of two ACARP research projects during 2000 and 2002. This method has proven to provide conservative upper bound predictions in the majority of cases. As the mechanisms and the factors which influence valley related movements are better defined, refinements in the method of prediction can be made so that the level of conservatism in the current method of prediction can be reduced.

Keywords: valley related movements, upsidence, closure.

1. Introduction

Valley bulging movements are a natural phenomenon, resulting from the formation and ongoing development of the valley, which has been well documented in literature. These movements can be accelerated where an excavation is made in the ground or underground, such as longwall mining. Natural valley bulging movements are illustrated in Figure 1.

Where longwall mining occurs near the valleys of rivers and creeks, the observed subsidence in the bases of the valleys are generally less than that those which would be expected in flat terrain. In addition to this, the observed horizontal movements of the valley sides are generally greater than those observed in flat terrain.

The additional movements within the valleys of rivers and creeks resulting from longwall mining are referred to as *valley related movements*. These movements are commonly observed in the Coalfields of New South Wales where valleys have been directly mined beneath or have been located near longwall mining.

Valley related movements are generally described by two components, being *upsidence* and *closure* movements.

Upsidence is the reduced subsidence, or the net uplift which results from longwall mining. These movements are commonly observed along survey monitoring lines as an irregular uplift at one or more survey pegs, typically located near the bases of valleys.

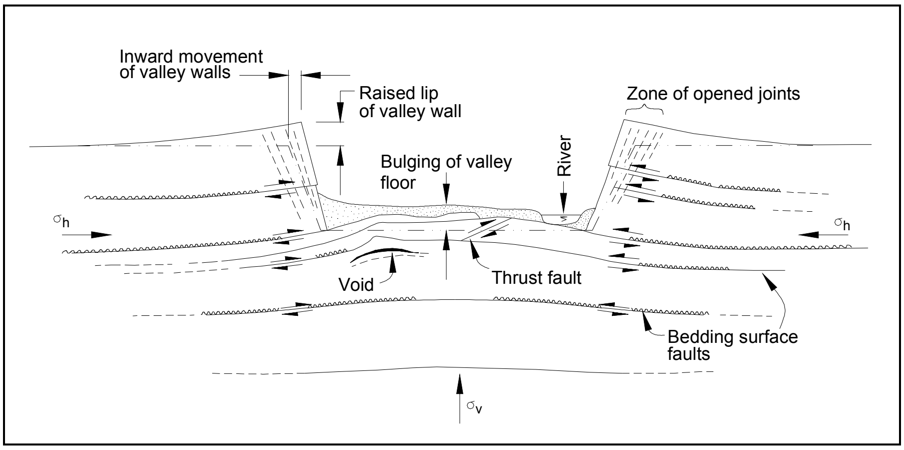


Figure 1 – Illustration of Upsidence and Closure Movements in a Valley (Fell, MacGregor and Stapledon 1992, based on Patton and Hendren 1972)

Closure is the reduced horizontal distance between the valley sides. These movements are also commonly observed along survey monitoring lines as reduced distances in one or more successive survey bays. The greatest reduction in bay length, or the greatest compressive strain, is typically observed near the bases of valleys.

2. Review of Mechanisms

Valley related movements were first observed in the Southern Coalfield of New South Wales back in the 1970's and 1980's, however, at this stage these movements and the implications of these movements were not well understood.

The first major research into upsidence and closure was not undertaken until the 1990's and it was only around this time that the potential impacts of upsidence and closure on the natural environment and surface infrastructure were appreciated.

Detailed subsidence monitoring at numerous Collieries within Coalfields of New South Wales have allowed a better understanding of the mechanisms and factors affecting these movements. Some of the factors known to influence valley related movements include:-

- Longwall geometry, such as panel width, panel length and chain pillar width,
- Depth of cover, seam extraction height and direction of mining,
- Position of longwall within a series of longwalls and previous adjacent mining,
- The magnitude of subsidence resulting from mining,
- Distance of the valley from mining, orientation of the valley to mining and whether the valley is directly mined beneath,
- Height, width and shape of the valleys, as well as the topography in the vicinity of the valleys,
- Geology in the overburden and in the base of the valley, including the type of strata, bedding, jointing and geomechanical properties, and
- Composition of the valley sides, whether comprising clifflines, large talus slopes or colluvium.

The number of factors and the complexity of valley related movements suggest that there are a number of mechanisms which result in these movements.

The mechanisms and the factors affecting valley related movements have been discussed by a number of authors, some of which are described in the following sections.

2.1. Movement into the Goaf

A detailed study of the affect of mine subsidence on steep slopes and cliff lines was undertaken by Kay (1991), as part of NERDCC Project No. 1446 undertaken by the Department of Mineral Resources.

The objective of the study was to improve the understanding of strata mechanisms involved when a steep slope or cliff is undermined and to formulate appropriate methods which could predict the ground movements near such topography.

The study included a monitoring programme over nine cliffs at Baal Bone Colliery which were directly mined beneath by longwalls having void widths of 212 metres, at depths of cover ranging between 120 and 200 metres.

The movements along the cliff lines were monitored using Electronic Distance Meter (EDM) measurements taken from reflectors attached to the cliff faces. It was noted in the study that this form of monitoring is not as accurate as traditional survey monitoring, however, it provided a safe and reliable form of measurement for the project.

The monitored cliffs lines were predominately orientated transversely to the extracted longwalls. It was found from the monitoring data that the surface topography had a significant influence on the observed horizontal movements.

Where the cliff lines were mined from under the plateau towards the valley, the tops of the cliffs were consistently observed to move towards the valley, that is, in the direction of mining.

Where the direction of mining was parallel to the cliff lines, the average horizontal movements were also observed to move towards the valley, that is, perpendicular to the direction of mining, regardless of the relative locations of the extracted longwalls.

Where the direction of mining was from the valley toward the plateau, the horizontal movements were much less, but still predominantly in a direction toward the valley.

The findings from these observations were that the horizontal movements at the cliff lines were vastly different to those observed in flat terrain, with the predominant movement being towards the valley and downslope.

Based on the observations at Baal Bone Colliery, a mechanism for horizontal movements at steeply sided terrain and cliff lines was proposed, which is illustrated in Figure 2 and is described below.

The strata immediately above a longwall extraction collapse into the void. The loose blocks of strata above the seam, near the edges of the extraction zone, move horizontally as well as vertically as they fall into the void.

Above the collapsed zone, the strata remain relatively intact and bend into the void. The sag of each strata layer results in a horizontal force on the overlying strata towards the extracted goaf. The strata sag and, hence, the horizontal forces directed towards the goaf reduce closer to the surface.

Where a cliff line is located near a longwall extraction and is parallel to the direction of mining, as shown in Figure 2, the horizontal force towards the goaf, directed from the plateau towards the valley, is not counterbalanced by a similar horizontal force from the valley towards the plateau. This results in a net horizontal force directed away from the extracted longwall and causes a horizontal valley closure movement at the cliff line. It is conjectured, that the horizontal movement occurs until the horizontal force in the strata is balanced by the frictional forces between the strata layers.

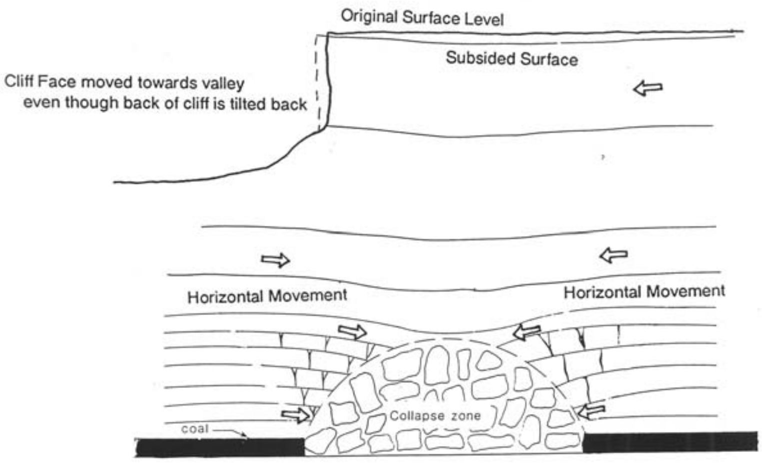


Figure 2 – Two Dimensional View of Effect of Extraction on a Cliff Line (Kay 1991)

2.2. Lateral Dilation

A refinement of the model forwarded by Kay (1991) was presented by Mills (2001) based on observations of horizontal movements at Baal Bone Colliery over a 15 year period. Based on this monitoring data, Mills suggests that the observed horizontal movements comprise three components.

The first component occurs as horizontal movement towards the goaf, as the longwall extraction face approaches the location being monitored. This first component is predominantly tensile or stretching in nature.

The second component is associated with horizontal movement towards the longwall face, and commences soon after the longwall face passes the location being monitored. Within the longwall panel, this component is predominantly compressive in nature.

The path that a point on the surface follows during the longwall extraction, therefore, depends on its position relative to the panel.

Monitoring points located above the extracted longwalls initially move towards the extracted goaf area and are subject to stretching. Then, once the extraction face has passed, movement occurs in the direction of mining and the overburden strata are compressed.

The components of horizontal movement observed outside the extracted longwalls are similar, although outside the mining area both the first and second components are in the same general direction toward the longwall resulting in a "dog-leg" path and there is no compression of the overburden strata.

A third *downslope* component of horizontal movement is observed where longwalls mine beneath sloping terrain. The direction and magnitude of this component is governed primarily by the direction and steepness of the slope, rather than the direction of mining.

Downslope movements tend to be greater than the other components of horizontal movement in locations of steeply sloping terrain, such as at cliff lines and across valleys. The downslope movements result in a net closure across valleys, regardless of the location and direction of mining.

Once the longwall extraction face has passed beneath the valley, the downslope movement and the movement towards the extraction face are in the same direction for the valley side initially mined beneath. Also, the downslope movement and the movement towards the extraction face are in opposite directions for the valley side subsequently mined beneath.

Where a longwall mines beneath a valley and is perpendicular to the valley, therefore, the side of the valley initially mined beneath moves more toward the valley than the side of the valley which is subsequently mined beneath.

Mills also observed that greater horizontal movements are observed when there is a coincidence of tensile or stretching behaviour in the overburden strata with unbalanced dilational forces associated with downslope movement.

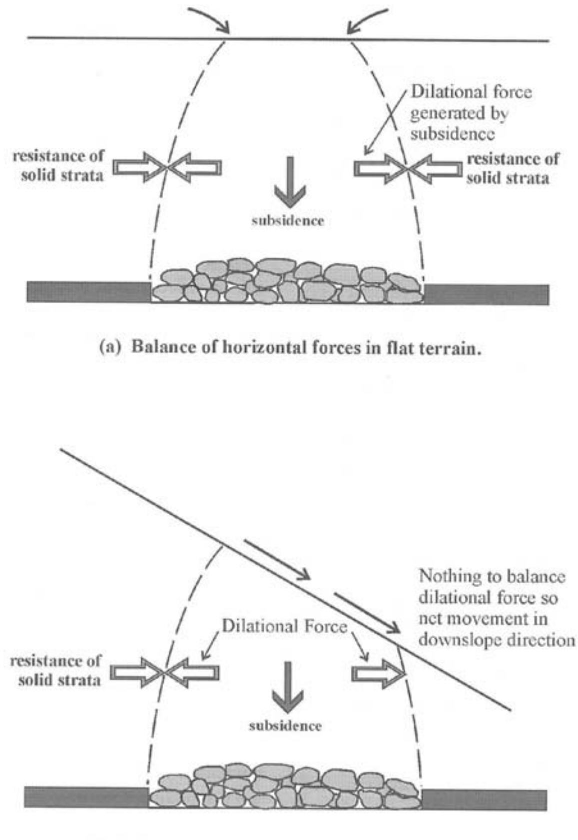
As a longwall extraction face approaches, the first component of horizontal movement causes the surface to undergo a tensile or stretching phase.

When this first component stretching phase coincides with unbalanced dilational forces in the overburden strata, the downslope movements are observed to be much larger than when there are either no unbalanced dilational forces (flat terrain) or the overburden strata is in the second component compressional phase.

As the overburden strata subside into the goaf, the blocks of strata cannot subside uniformly as one because the mining process is incremental. Individual blocks of rock within the overburden strata must move downward relative to each other. This relative movement of adjacent blocks, either through rotation or differential shear, causes lateral dilation or sideways forces that are driven by the downward movement or vertical subsidence.

In flat terrain, the horizontal dilational forces within the goaf are counteracted by the solid strata on either side of the goaf, as illustrated in Figure 3(a).

In sloping terrain, there is less resistance to the dilational forces on the downslope side of the longwall goaf, resulting in downslope movement, as illustrated in Figure 3(b).



(b) Unbalanced dilational force in sloping terrain.

Figure 3 – Mechanism for Downslope Movement (Mills 2001)

Observations indicate that the greatest downslope movement occurs during the stretching or tensile phase of the horizontal movement.

When mining occurs in the downslope direction, or from under a plateau towards a valley, the unbalanced dilational forces associated with the topography occur on the slope at the same time as the slope is going through the stretching first component of horizontal movement. The coincidence of these is found to result in greater potential for horizontal movement.

When mining occurs in the upslope direction, the stretching or tensile phase is over before the unbalanced dilational forces associated with vertical subsidence on the plateau have been generated. By the time they are generated, the slope has gone into the second component compressional stage and the potential for downslope movements is curtailed.

Based on the observations at Baal Bone Colliery, as well as a number of other Collieries in the Western and Southern Coalfields, it is considered likely that downslope movements form an important component of valley closure movements.

While dilational forces develop directly over the mining area, the lateral movements that they induce can extend well outside of the mining area in sloping terrain when the geological conditions allow.

2.3. Blocky Model

Another type of blocky model was also used to describe a mechanism for valley related movements by Seedsman and Dawkins (Release Pending 2007), as part of ACARP Research Project No. C23020.

The model comprises a series of large blocks which are supported by an underlying surface. Incisions in the surface, such as river and creek valleys, can be modelled by providing spaces between adjacent blocks.

When the underlying surface is deformed, for example due to systematic subsidence, the blocks rotate and move horizontally towards the incisions. This is illustrated in Figure 5.

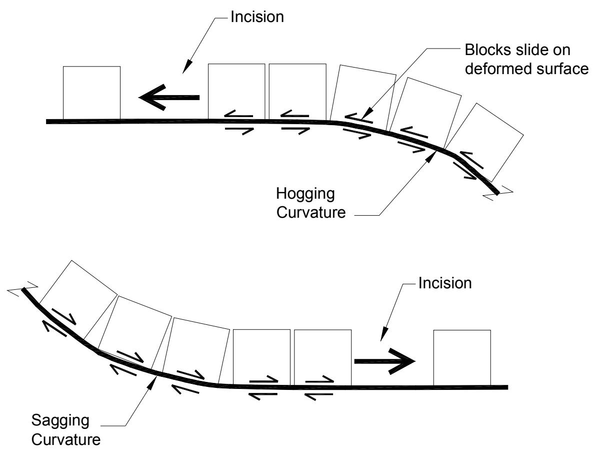


Figure 5 – Blocky Model Illustrating Horizontal Movements Resulting from Surface Deformation

This type of model provides a mechanism for horizontal closure movements at incisions located within the limit of systematic subsidence, at locations of both hogging and sagging curvature.

This type of model also provides a mechanism for horizontal closure movements at incisions beyond the limit of systematic subsidence, however, only on the valley side closest to the extraction.

Where the valleys are parallel to the longwalls, the horizontal movements are generated by the ground curvatures orientated transversely to the longwalls.

Where the valleys are perpendicular to the longwalls, the horizontal movements are generated by the ground curvatures orientated along the lengths of the longwalls at the commencing and finishing ends of the longwalls, as well as at the longwall extraction faces.

The location of the sliding plane can be also used to describe the mechanism for upsidence.

Where the sliding plane is located below the base of a valley, and the strata in the base of the valley is not sufficiently strong to sustain the induced horizontal forces from the adjacent blocks, the unrestrained strata buckles resulting in an upsidence movement.

Where the sliding plane is located above the base of a valley, the closure movements do not result in an induced horizontal force at the base of the valley and are less likely, therefore, to result in an upsidence movement.

2.4. Stress Related Mechanism 1

An empirical method of prediction for valley related movements was developed as part of ACARP Research Project No. C8005 in 2000 and ACARP Project No. C9067 in 2002 (Waddington and Kay 2002).

The study was based on a large database of observed valley related movements, primarily from the Cataract and Nepean River Gorges in the Southern Coalfield.

The Cataract and Nepean River Gorges are steeply sided, having valley heights ranging between 40 and 70 metres. The valley sides comprised cliff lines formed within the Hawkesbury Sandstone.

The observed horizontal closure movements across the Cataract and Nepean River Gorges were found to be relatively uniform over the heights of the cliff lines. In these cases, therefore, downslope movements were not considered to be the major mechanism resulting in the observed valley closure movements.

In stating this, however, downslope movements are not discounted as an important mechanism for valley related movements in other cases, such as valleys containing large talus slopes or colluvium.

In cases where valleys contain massive cliff lines, it is conjectured that redistribution of horizontal in situ stresses is a major mechanism in the generation of valley closure movements.

High levels of horizontal in situ stress are found in the Southern Coalfield of New South Wales with the horizontal stress greater than the vertical stress in most cases.

Where longwall mining occurs, the horizontal in situ stresses in the strata are redistributed around the mined void and the collapsed zone above the void. This is illustrated in Figure 4.

The redistribution of horizontal in situ stress results in a greater horizontal stress in the strata above the collapsed zone and beneath the extracted void. It is possible that this redistribution of horizontal in situ stress could occur for several kilometres beyond extracted longwalls.

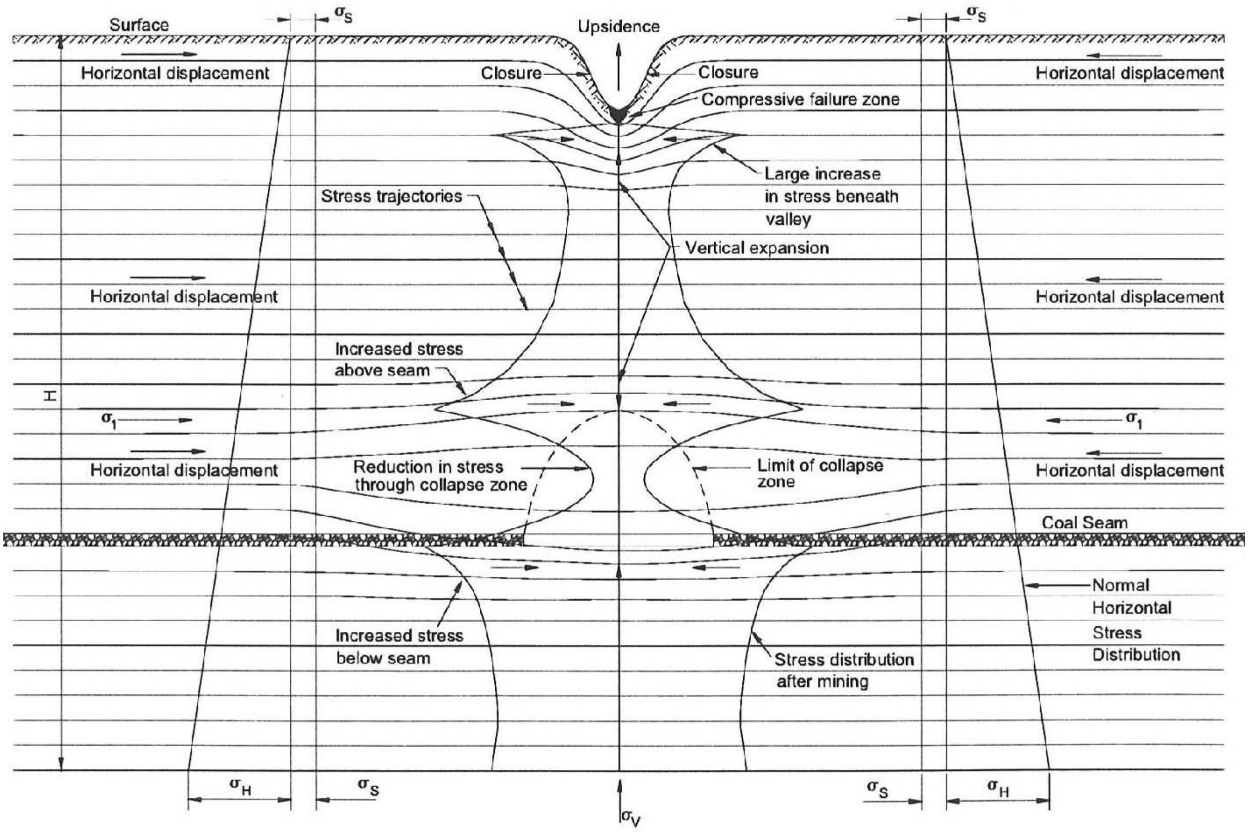


Figure 4 – Redistribution of Horizontal In Situ Stresses due to Mining Beneath a Valley (Waddington and Kay 2002)

The redistribution of horizontal in situ stress is concentrated at any incisions in the surface, such as at the bases of river and creek valleys.

The strata in the bases of valleys are not constrained vertically and a local increase in horizontal stress results in an upwards dilation of the strata in the base of the valley and a closure movement across the valley.

Where the strata in the base of the valley are not sufficiently strong to support the increased horizontal stress, the strata buckles and the upsidence profile takes the shape of a localised spike.

The redistribution of horizontal in situ stress as a result of longwall mining can be used to explain valley related upsidence and closure movements above longwall extractions, as well as outside the limit of systematic subsidence.

Although the redistribution of in situ horizontal stress was suggested as a major component of valley related movements for the Cataract and Nepean River Gorges, this factor could not be isolated from the monitoring data at the time of these research projects.

A definitive model based on the redistribution of horizontal in situ stress could not be established, so a conservative empirical upperbound prediction model was established based on all monitoring data, regardless of magnitude and orientation of horizontal in situ stress.

It has been found that, in the majority of cases, observed valley related movements are typically between 50 % and 100 % of those predicted using the ACARP method and, in some cases, observed movements are less than 25 % of those predicted. In rare cases, however, it has been found that the observed movements exceeded those predicted, which is generally thought to be the result of low strength rock strata in the valley floor.

Refinement of the ACARP method of prediction is expected to be possible as the mechanics of valley closure movements are better understood. With refinement of the method, the level of conservatism that is currently built into the current method can be reduced.

2.5. Stress Related Mechanism 2

A second stress related mechanism that may contribute to valley closure events occurs when the vertical stress acting on critical bedding planes near to river channels disturb the state of equilibrium on bedding planes that daylight in or are close to the base of river channels.

The horizontal stresses that are locked up in the near-surface rock strata as a result of tectonic activity are balanced by inclined stresses that dip under deeply incised river channels such as the Cataract River Gorge. These inclined stresses are likely to be at limiting equilibrium along bedding planes that daylight in or are just below the base of the river channel.

A state of limiting equilibrium occurs when the weight of overburden rock is just sufficient to maintain frictional resistance along the bedding planes. The angle at which the horizontal stresses can dip under the river channel is limited by this frictional resistance.

Vertical stresses in the strata directly above each longwall panel are redistributed during the subsidence process, with the result that the state of limiting equilibrium that exists on the bedding planes can be disturbed. When this equilibrium is disturbed, lateral movement occurs on the bedding planes, predominantly in the direction of the major horizontal stress, until equilibrium is re-established. Valley closure occurs as a result of this lateral movement.

This phenomena tends to occur as a single, relatively sudden event, rather than incrementally as subsidence develops. The movement tends to be in the direction of the major horizontal stress, which in the Southern Coalfield is typically oriented just north of east. This mechanism is considered to be only one of the mechanisms that contribute to valley closure and is not observed at all sites.

3. Conclusions

As described in this paper, there are believed to be a number of mechanisms which contribute to valley related movements as a result of longwall mining.

The relative contribution from each mechanism is expected to vary from case to case, depending on a number of factors including mining geometry, valley geometry, geology and composition of the valley sides.

The existing ACARP method of prediction for valley related movements is based on conservative upperbound prediction curves, as a number of these factors have not been isolated in the model.

As the mechanisms and the factors which influence valley related movements are better defined, refinements in the method of prediction can be made, that is, the level of conservatism in the current method of prediction can be reduced.

4. References

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