Surface Subsidence Prediction in Barapukuria Coal Mine, Dinajpur, Bangladesh

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Abstract

As a part of the evaluation of long wall caving mechanism of the 1101 coal face of the Barapukuria coal mine (BCMC), Barapukuria, Parbatipur, Dinajpur district, Bangladesh, analysis of horizontal strain and subsidence that would be expected at the ground surface over long wall coal face was performed. To extract coal, the Barapukuria Coal Mining Company (BCMC) adopts the method of Inclined Slicing of Roof and Caving Long Wall Mining along the Strike, and the sequence of slices is from top to bottom. Mining of 1101 coal face triggered caving of the lowest strata in the roof and propagated upward into the Gondwana Formation and even up to the base of lower Dupi Tila and finally reached the surface. In the NCB (England, 1975) method, it is estimated that at around 0.75 m of ground subsidence may occur due to the mining of 1st slice, and successively, the mining of 5th slice may result in a ground subsidence of 2.25 m, and it may be difficult to control the ground response and violent interaction effects are anticipated. Back filling process can not eliminate subsidence but reduce it, if carried out to a higher standard and allows an increase in the percentage of recovery of the coal over the caving mining methods. Such high risk mining methods must be avoided because the failure would seriously jeopardize any future mining prospects in the country. The results of this research work may serve as basic guidelines in long wall planning and design of the mine and are suggested for incorporation by the mining authority.

Introduction

Coal mine of Barapukuria basin in Dinajpur district, enters into the coal mining era for the first time. During field seasons 1984-85 and 1986-87, Geological survey of Bangladesh (GSB) drilled seven boreholes in and around Barapukuria area under Parbatipur Upzilla of Dinajpur district, (Fig.1) and confirmed the presence of 157 m thick Gondwana sediments between the basement and Tertiary sediments. The country has no coal mining experience in the past and BCMC is expected to carry out all the mining related activities in the country. Barapukuria coal mine is organized by the Jiangsu Coal Geology Company, CMC, China, under the direct supervision of Petrobangla, Bangladesh. As of now, trail basis production is under progress, which is a modern and large scale one with a production capacity of 1 million tonnes annually.

From the underground coal mining and environmental standpoint, all surface effects of subsidence associated with mining must be recognized. The analysis of vertical displacement that will impact mining operations has often been the primary focus of subsidence investigations. This research work is intended to provide primary focus on the impact of mining operations of 1101 long wall face of BCMC, and consequent direct surface effects. The major components of subsidence that influence its environmental are -vertical displacement, horizontal displacement, slope, horizontal strain, and vertical curvature (SME, 1986). The BCMC is the first organization entering Bangladesh and starting the coal mining era, very little

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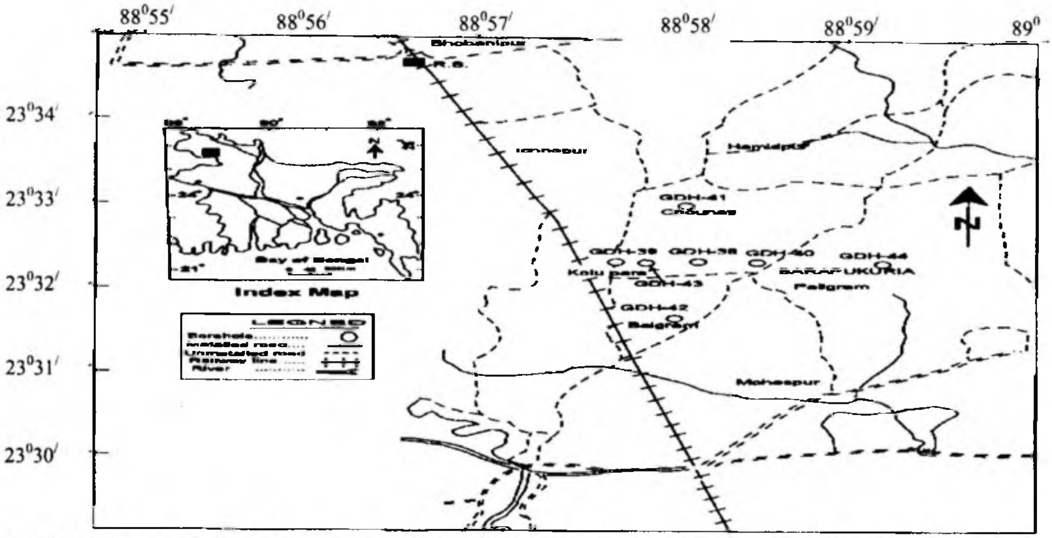

Fig. 1: Location map of the Barapukuria Coal Mine area, Parbatipur, Dinajpur District, Bangladesh.

information is available concerning subsidence prediction model, particularly the stress-strain behavior of litho-stratigraphy of Bangladesh and as such existing information is not sufficient enough for a detail analysis of subsidence model. Hence, the empirical Graphical method is used for the prediction of surface subsidence as a consequence of BCMC field operations.

Methods of Study

The most comprehensive and widely used empirical method of predicting subsidence and surface strain profiles is that developed by the National Coal Board, UK and reported in the NCB's subsidence Engineers hand book (1975). This method is to represent the effects of major factors by a series of nomographs based on numerous movement and deformation curves collected under similar mining conditions and geological setting. The method becomes more widely used under a wide range of situations and it is easiest and convenient to use. Although this method is only and strictly applicable to the UK, it is not unusual to use the method as a basis for preliminary development work in other coal fields. As locally observed, and with more added information, the empirical model of subsidence prediction for BCMC is more relevant to NCB's method. It is observed that there is a significant variation in the predicted values for the subsidence and strain profiles of the NCB and locally derived BCMP prediction model. It is noted that in absence of any local data the use of NCB method can be considered appropriate for the purpose of the study. Again, the subsidence profile predicted by this method depicted a variation of ±10% of the actual field measurement, (NCB, 1975; Peng, 1986). The NCB prediction model is used in the case of 1101coal face trail basis production stage of BCMC with some limitations, due to the absence of available mining data and obviously the practical condition of gob forming process.

Subsidence Prediction of 1101 Coal Face

It is difficult or even impossible to thoroughly measure the displacement of the upper strata due to subsidence caused by mining activity in the targeted coal horizon. Most of this research on subsidence is based on the surface movement of the mining area. Theories or methods for subsidence prediction, damage assessment and prevention measures have been established based on surface measurement. However it is believed that the subsidence phenomenon in any underground substance is similar to that at the surface. Thus by adopting the surface subsidence theory to the upper seam in a multiple seam mining environment, the location and extent of tension and compression zone in the upper roof strata can be predicted with acceptable accuracy.

The BCMC is now engaged in trail basis production mode and the 1101 coal face is going to be prepared for the extraction of coal, and only 50 m of the long wall face is to be developed. The overall geometric layout of 1101 face has a thickness of m = 2.5 m, depth of seam or overburden, h = 250 m, width of the long wall face, w = 103 m, rate of advancing speed of shearer cutting = 5 m/min, one cycle of complete cutting by double drum shearer is 30~33 min. A brief analysis of 1101 long wall coal face of the BCMP and subsidence prediction assessment was carried out by the empirical graphical method (NCB, 1975), which is given below:

Calculated Sequences, Results and discussions

Limit angle and Subsidence development:

When the mined-out gob has reached the critical size, the angle between the vertical line at the face edge and the line connecting the face edge to the movement basin, is the angle of draw. Theoretically, it varies from 15° to 45° (Allgaier, 1982) depending on the location, size of opening, and the local geology. Incase of BCMC, the limit angle or angle of draw is assumed to be 35° from the vertical plane (Wardell Armstrong, 1993) shown in Fig 2. According to Peng, 1984, the limit of subsidence development is approximately 0.7 h in front and 0.7 h behind a working face. From this point of view, the influence of subsidence initiates by a circle of diameter of 175 m from the edge of the Track gate and Belt gate crosscut to the retreating direction of the 1101 coal faces upper strata.

Maximum Possible Vertical Subsidence (Smax)

Theoretically, the maximum possible vertical subsidence that can occur when complete mineral extraction and subsequent roof caving has taken place within the circle of influence is 90% of the seam thickness. i.e. S max = 0.9 m

Maximum Vertical Subsidence (S) in Relation to the Width/Depth Ratio (w/h)

For a given width of the long wall face(w), the maximum vertical subsidence (S) decreases with increased seam depth (h) and vice versa. The value of S can be calculated for subsidence profiles from Fig.3.

In the case of BCMP the extracted width of the 1101 Coal face to be W=103 m, thickness of coal seam, m=2.5 m and the depth of over burden h = 250 m. The calculated maximum or central subsidence, as

$$=0.3,\ S = 0.3 \times m,\ Or,\ S = 0.75\ m$$

Vertical Subsidence (s) away from the Centre Point of the Working:

The vertical subsidence (s), distance X from the centre of working may be expressed as:

$$s = K1 \times S$$

The coefficient K1 is plotted against various values of X/L in Fig.4 for the construction of detailed subsidence profile.

Fig.4.Vertical subsidence away from centre point or critical axis of the mine working.

Horizontal Displacement (V)

The horizontal displacement (V) associated with a vertical subsidence (s) at a distance X from the critical axis is given by:

$$V = K2 \times s$$

The coefficient K2 is plotted against X/L for the values of w/h = 0.412 in Fig.5. Here it is noted that, all final horizontal displacements are moving towards the central axis of the working face.

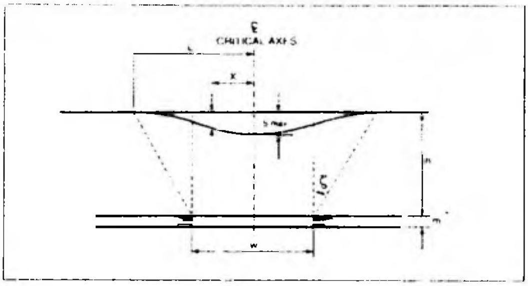

Fig. 2: Terminology for subsidence profile above a single long wall coal face.

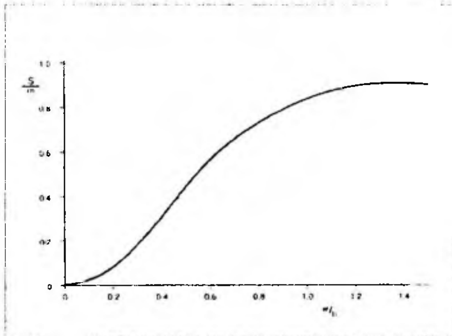

Fig. 3 : Subsidence related to Width / Depth ratios of 1101 coal extraction.

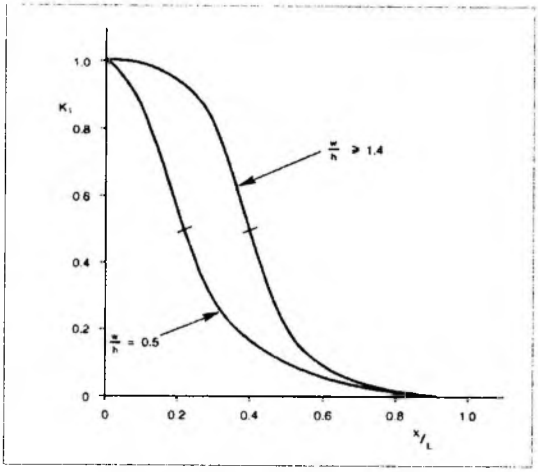

Fig. 4 : Vertical subsidence away from centre point or critical axis of the mine working.

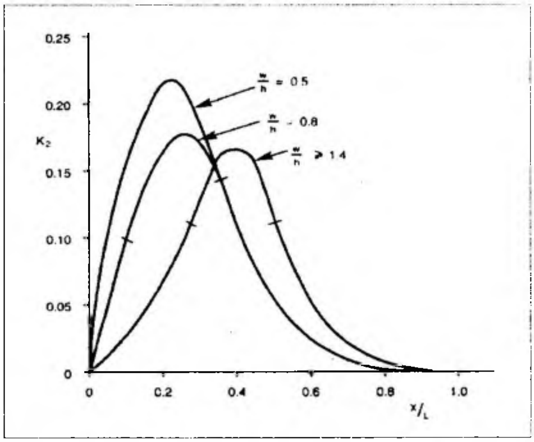

Fig. 5: Horizontal Displacement away from the centre point or critical axis of the face in terms of width/depth of the extraction.

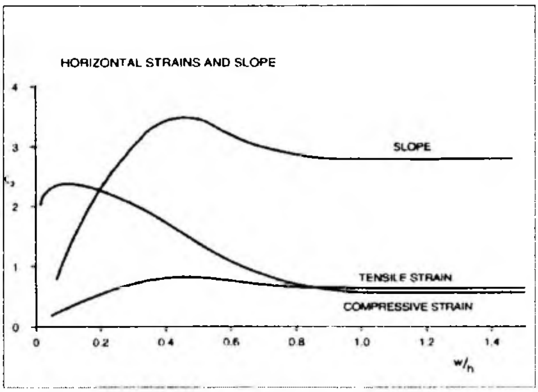

Fig. 6: Horizontal strain and slope at various Width/ Depth ratios of extraction.

Horizontal Strain (± E)

Horizontal strain or change in unit length (± E), can be derived from horizontal displacement by considering two points at a small distance apart, from Fig.6.

i.e. Strain (± E) = S dK2/L

The maximum strain is related to the maximum subsidence and depth of overburden of the rock mass. The proportional constant K3 is determined from fig.6, which is depending on the w/h of the working face and it is different for both the tensile and compressive strain.

From Fig.6, it is estimated that K3 =0.8 for compressive strain (+E) and K3 = 1.65 for tensile strain (-E) in the prevailing condition for the BCMC 1101 coal face ground surface.

Ground Slopes or Rotations (G)

Change in ground slope or rotation (G) can be derived from vertical subsidence by considering two points at a small distance apart, fig.4.

.ie. Rotation (Gmax) = Smax dK1/L

A more accurate estimate of maximum rotation in a subsidence trough may be obtained from the expression:

$$G = K3\ S/h$$

Like subsidence and strain profile, the slope profile may vary with the w/h of the opening. The maximum slope is greatest for an opening with w/h= 0.45 and decreases with increase or decrease of w/h (Peng, 1984). Now the coefficient K3 is plotted against w/h (Fig.6). and the maximum possible slope is given by:

$$Gmax = 2.75\ Smax/\ h$$

Subsidence Profile

The complete subsidence profile determined from the graph, which can be expressed in a table given below:

In Table-1. Row 1 lists the steps of the ratio of local subsidence to maximum subsidence (s/S) as 0 (Zero) for the subsidence edge and 1 for the center point of the face. The number and interval of steps of the calculation sequence are arbitrary. Multiplying each step in row 1 by maximum subsidence (S=0.75) to obtain row 2, which physically signifies the local subsidence that may have happened in the upper strata of the mining horizon of 1101 coal face.

The horizontal displacement is determined (in Row 3) based on the calculation from Appendix of NCB, 1975. The value X/L (where, X is the distance from the center of the face) is estimated for w/h=0.412. Then multiplying each value of Row 3 by overburden depth, h =250m, to obtain the actual distance from the center of the face for Row 4is obtained. Basically, Row 2 lists the actual subsidence for points listed in corresponding columns of row 4. The predicted final subsidence profile is shown in Fig.7.

Strain Profile

Like subsidence profile the strain profile can be constructed, by following similar procedure. In Table. 2 the computed value for a complete strain profile is given:

The row 1 lists values of horizontal strain e/ E of Appendix of NCB, 1975, & row 2 is the product of K3 ×S/h (where S=0.75, and h=250 m).Row 2 is obtained by multiple fractions of row I, where K3 is the proportional constant. Therefore, Row 3 is derived by transferring the distance in terms of 'h' for W/h = 0.412 (Appendix of NCB, 1975). Basically, it is the relative displacement of the upper strata due to the mining of target horizon, which can be from the centre point of the workings to the rib side of the face. Hence, it is regarded as the empirical assumption which can not be determined in the practical field condition. Now multiplying row 3 by h = 250 m to obtain row 4 in terms of distance from the center of the opening, the iteration of calculation sequence for strain profile is completed. Now, the strain profile is graphically presented by using the value of row 2 and row 4, which is the final predicted strain profile for the maximum subsidence of S=0.75 m, shown in fig.8.

Final Subsidence Profile

As a part of the evaluation of long wall caving

Table 1: Calculation sequence for the determination of subsidence profile.

Subsidence as S	0	0.5	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95	1
Subsidence (m)	0	0.03	0.07	0.15	0.22	0.30	0.37	0.45	0.52	0.60	0.67	0.71	0.75
Displacement in terms of X/L (m)	0.91	0.59	0.47	0.34	0.28	0.24	0.20	0.17	0.15	0.12	0.08	0.06	0
Horizontal displacement (m)	227.5	147.5	117.5	85	70	60	50	42.5	37.5	30	20	15	0

Table 2: Calculation sequence of predicting strain profile.

Strain as e/E	0	0.20	0.40	0.60	0.80	1	0.80	0	0.2	0.40	0.60	0.80	1
Strain in 10^{-4} (m)	0	4.8	9.6	14.4	19.2	24	19.2	0	4.8	9.6	14.4	19.2	24
Distance in terms of h (m)	0.91	0.60	0.51	0.44	0.39	0.31	0.27	0.20	0.18	0.15	0.11	0.07	0
Distance (m)	227.5	150	127.5	110	97.5	77.5	67.5	50	45	37.5	27.5	17.5	0

mechanism of 1101 coal face of BCMC, an analysis of horizontal strain and subsidence that would be expected at the ground surface over long wall coal face was performed. This section of the report provides a general discussion of subsidence effects, the input parameters and NBC empirical method used for the analysis, and the predicted horizontal strain and subsidence displacements obtained by these analyses. The long wall coal mining is designed to recover large blocks of coal and left almost no coal prior to support the surface. Historically, long wall mining method results in a larger area of subsidence troughs than the conventional room-and-pillar mining. Generally, due to long wall mining, vertical subsidence may occur at the surface along the centerline of the face, which depends upon seam thickness, overburden rock over the coal seam, and the surface topographic features.

Mining induced surface subsidence, ultimately results in causing damage to the surface features and structures. The magnitude of damage depends on the forces (stress) that propagate to the surface as the mine roof collapses. These forces may include stretching (tension), squeezing (compression), and sinking of the ground (vertical displacement). The effects of the forces are measured and studied by developing a subsidence profile, which shows how subsidence would look on a cross-section, usually drawn at right angle to the long wall face advance. From the constructed profile (Fig.7), it is shown that the greatest amount of vertical displacement may occur along the lengthwise centerline of the 1101 long wall coal face. The average vertical subsidence may vary from 0.75 m at the center of the face to 0.03 m at the edge of the face. Subsidence basin may initiate at a distance of 25 m from the cross cut road way towards the center line of the studied coal face, where as the maximum vertical displacement is calculated as 0.75 m from the cross cut entry to the coal face at a distance of 240 m. i.e. the subsidence trough progressively decreases at a point along the trough of the profile until the limit of the affected surface area is reached.

The figure shows that at the center of the face, a maximum subsidence of 0.75 m is calculated with no measurable change in slope. Subsidence (vertical displacement) has decreased from the center of the face to the edges. Inclination or curvature reached maximum levels at approximate midpoints between the centerline and the face edges. The study also examined the horizontal displacement created by the subsidence event. Given the ground sinks from less than unity at the face edges to maximum at its centerline, the surface experienced measurable horizontal movement. Fig 8 shows the horizontal displacement that may be observed at the 1101 coal face, projected to the ground surface.

Approximately at midpoints between the centerline and the face edges, horizontal displacement was minimum, where as at the trough edge it shows the maximum value of 24×10-4 m for single coal face extraction. Surface features and structures above the long wall face will experience varying levels of stress and subsequent deformation depending on specific location above the face. Where as the ground slope or rotation value represented negligible degree of changes as per the predicted profile over the coal face. Another profile shows that both the horizontal and the vertical forces of tension

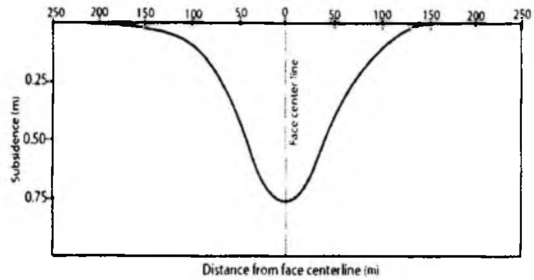

Fig. 7: Predicted subsidence Profile over 1101 Long wall face.

and compression move in a wavelike motion along the surface, slightly ahead of the advancing longwall face. A schematic view of this process depicts how the surface is subjected to waves of stretching (tension) and squeezing (compression) as the longwall face passes. The advancing wave creates a tensional force and then changes to a compressional force, shown in Fig.9.

This simplified model gives a prediction of maximum subsidence expected along the centerline of a panel. Tensile and compressive stress-strain fields and vertical and horizontal deformations develop at the surface due to the collapse of the long wall cavity. The purpose of the subsidence analysis was to determine locations of relative highs in surface tensile and compressive strains at undermined study sites for correlation to stressed areas. Surface tensile

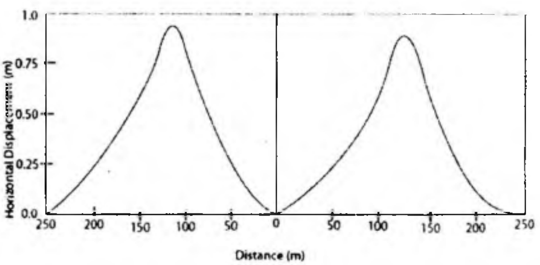

Fig. 8: Horizontal Displacements over the 1101 Long wall coal face.

strains are more likely to cause damage than surface compressive strains because of the possibility of tearing of the ground surface or shallow gushing of groundwater into surface cracks.

Again Professor Whittaker of Nottingham University, U.K (1990) carried out a pre feasibility study for BCMC. In his report, it is calculated that for mining of 1st slice the maximum subsidence is about 0.60 m in case of 2.5 m seam height. Progressively increasing the number of slices up to 6, the resultant subsidence would be expected 3.6 m at the ground surface. Where as in this research work it is calculated that after extraction of 5th slice the ground surface above the extracted coal face to be 3.75 m. So it is opined that the mine authorities should take this analogical comparison between the studies, as a means of mine fate, lest a deadly event may occur in the country's first mining industry.

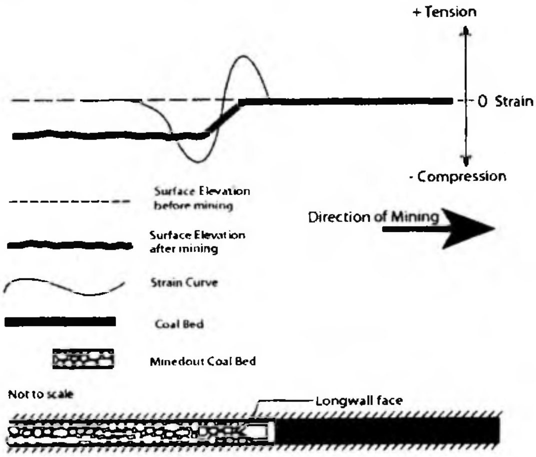

Fig. 9: Compression and tension due to Movement of 1101 long wall coal face; Profile parallel to the face.

Conclusion

With the advancement of long wall face in the coal seam, the support from the overlying strata is detached and the original equilibrium of these strata is disturbed. The main concern relating to subsidence occurrence at the ground surface of the BCMC site is the development of subsidence trough. From the calculation, it is estimated that about 0.75 m ground subsidence may occur due to the mining of 1101 coal face of BCMC. The mine design plan expected that 5 slices will be mined out through the course of mine life.

From the analysis, it is estimated that the rate of subsidence is relatively high enough (0.75 m) in the case of 1st slice, wherefrom successively it may be assumed that after mining 5th slice the rate of ground subsidence may be 2.25 m, and relatively difficult to control the ground response and a violent effects anticipated. The development of subsidence trough above multi slice long wall face gives rise to the generation of fracture plane and opening of pre-existing weakness planes between the mining horizon and the surface. The generation of fracture planes sufficient to intercept a surface water body can give rise to the formation of a direct flow path between the surface and the mining horizon. A major fault or a sedimentary dyke can also be sufficiently opened up by the undermining as to allow water body to drain into the mine workings below. Therefore, it is recommended to consider working a longer and more productive coal face to minimise the disturbance of the Gondwana Formations above the mining horizon, and to avoid increasing the risk of inundation from the Dupi Tila Formation. It is also emphasized to carry out a detail study of the ground response and expansion of the materials.

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