Subsidence Management in Jharia Coalfield, India
— A Concept

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ABSTRACT Jharia coalfield in India having been blessed with about 17-billion tonne coal in 40 coal seams is facing problems of subsidence management due to successive extraction of the seams. More than 50 Km$^2$ of land in the coalfield has so far been degraded. Many surface properties have been damaged. A maximum subsidence of about 25 m is anticipated in the coalfield. The subsidence shall be taking place repeatedly and therefore subsidence management measures shall have to be planned accordingly. A methodology for such a subsidence management has been suggested.

JHARIA COALFIELD

The importance of Jharia coalfield in India lies in the fact that this is the only source of prime coking coal in the country. From the point of view of coal mining India occupies an important position with about 205 million tonne production in 1989-90. The projected target for the year 2000 is 400 million tonne. As per available records coal mining in India was started in 1774.

The Indian coalfields, covering more than 15,000 Km$^2$ area, generally belong to Lower Gondwana group of Permian age and Tertiary group of Eocene to Miocene age. Lower Gondwana deposits account for 90% of the total coal production. The coal reserves of the country are estimated as 176,330 million tonne.

The Jharia coalfield is located in Dhanbad district of Bihar. It lies about 250 km west of Calcutta. Various details of the coalfield are listed below.

1. Longitude & Latitude - 86°11' to 86°27' and 23°39' to 23°48'
2. Ground elevation above mean sea level - 140 to 240 m
3. Surface topography - Slight undulations
4. Shape of coalfield - Sickle shaped coalfield
5. Average length - 40 km
6. Average width - 12 km
7. Area - 450 sq.km. (approximate)
8. Formation - Gondwana Group of Permian age
9. Measures - Talcher, Barakar, Barren & Ranigunj
10. Coal bearing measures - Barakar and Ranigunj
11. Number of coal seams - Barakar measures = 40
   Ranigunj measures = 10
12. Reserves - 17,077 million tonne
13. Rock mass composition (average) - Coal = 12%, Sandstone = 45%,
   Shales=20%, Intermixed sandstones and shales =16%, Jhama= 3%, and Sub-soil = 4%
14. Dip of seams - Generally flat. But up to 55°
   in extreme western part
15. Mining history - Mining was started about
   100 years ago in 1890.
17. Target for 2000 - 43 million tonne
18. Production from underground - 15 million tonne (1990)
19. Production target from underground for 2000 - 30% (17.2 million tonne)
20. Coal blocked below surface properties - 6,143 million tonne
21. Coal blocked below fires - 1,864 million tonne
22. Important surface properties - Rivers and Jores, e.g., Damodar,
   Jamunia, Khudia, Ekra, Katri, Chatkori, Kari, Sulunga, etc.
Roads, e.g., National Highways (No. 2 and 32), PWD, District Board and Private roads. The total length of roadway network in the coalfield may be around 500 km by the end of 1995.
Railway lines, e.g., Grand Chord of Eastern Railway, Adra-Gomoh link line of South Eastern Railway, and a network of local railways, railway yards and assisted siding. The total length of rail network in the coalfield was about 110 km in 1990.
Townships and Colonies (14 Urban and 113 Rural settlements), e.g., Jharia, a part of Dhanbad town, Karkend, Katras, Digwadih, Chasnala, Patherdih, etc. All constructions in these settlements are either Kutcha (mud construction), Pucca single and double storey without basement in general. There are only a few multistorey buildings.
Plants and Structures, like, thermal power plants, washeries, coal handling plants, ropeways, high and low tension transmission lines, small factories, pipe lines, bridges, etc.
24. Land use pattern (1989) - Mining and other industries=24%,
   Agriculture=11%, Forest=1.2%,
   Settlements=12%, TISCO, IISCO,
   Roads, Railways, water bodies, barren fallow land, etc. = 51.8%
25. Degraded land in BCCL leasehold (1989) - Area under subsidence=35 sq.km,
   Area under fire (70 fires)=17 sq.km, Area under dumps=6 sq.
   km, and Area under abandoned opencast mines=4 sq.km.
UNDERGROUND MINING SITUATION

As stated earlier, Jharia coalfield has about 100 years history of coal mining and has 40 seams in Barakar and 10 seams in Ranigunj measures. The present day (1990) mining situation in the coalfield is briefly described below.

1. Old workings - The yester-year mining practices in the field have left a legacy of unapproachable abandoned underground mine workings standing on small pillars in a large number of places. With the passage of time these workings have became waterlogged and their accurate plans are generally not available. Many of these workings are below and by the side of important surface properties.

About a dozen of the unapproachable old workings have subsided in recent past causing severe damages on the surface in the form of wide-cracks, large depressions, sink holes (pot-holes), blockage of roads and rails, damage to buildings and other surface properties, etc. The main characteristics of these subsidence were that - indications on the surface are seen only a few hours in advance, they do not follow any pattern, they cause marked depressions with wide cracks and stepping, and they are associated with rumbling sound.

2. Extraction thickness - Generally seams less than 1.2m in thickness are considered unworkable. The maximum extraction thickness may be up to 4.8m in one lift. In case of multi-lift and multi-section mining the extraction has been up to about 12m.

3. Depth - The underground workings in the coalfield are generally at depths less than 250m. Only about 20% of the workings are at greater depths. The maximum depths of the workings may be around 500m while the minimum may be about 15m.

4. Multi-seam extraction - As stated earlier there are 40 coal seams in Barakar measures and 10 in Ranigunj measures in the coalfield and the total thickness of seams is on average 12% of coal measures. In these conditions almost everywhere multi-seam mining has been done. In some situations two or three seams are standing on developed pillars.

5. Multi-section extraction - The maximum thickness of coal seams in the coalfield is around 20m. In the seams, more than 6-7m in thickness, multi-section development has been extensively done on bord and pillar pattern. Suitable methods of exploitation of the thick seams developed in two to three sections are being looked for.

6. Method of underground extraction - About 80% of production from underground mining is obtained by bord and pillar system and the remaining 20% from longwall mining.

7. Percentage of extraction - The percentage of extraction from the panels in workings without longwall system varied greatly from about 60 to 80 in both caving and stowing cases.
SUBSIDENCE IN JHARIA COALFIELD

Jharia coalfield is facing subsidence problems from the point of view of the presence of old workings which are generally waterlogged and about a dozen of them have subsided in recent past causing severe damages to surface topography and properties, extraction of coal seams below the old workings as also below workings standing on developed pillars, exploitation of coal seams below the old workings as also below workings and in the vicinity of surface properties, fires due to subsidence and then further subsidence due to fires and general degradation of surface land and environment.

Salient points of subsidence parameters in the coalfield after subsidence studies under the leadership of the author are described below.

1. Visual subsidence impacts of subsidence in Jharia coalfield over different categories of surface properties are as given below.

   (a) Subsidence up to about 500 mm were generally not visually felt in barren areas.
   (b) Subsidence up to a magnitude of about 650 mm over hydraulically sand stowed workings did not cause any visual distortion in the surface topography or impact on surface vegetation.
   (c) Over caved workings at depths up to about 100m discontinuous subsidence took place with stepping.
   (d) Over caved workings at depths less than 50m sinkholes/pot-holes were also developed.
   (e) Subsidence over unapproachable workings also caused pot holes, discontinuities and steps.
   (f) Discontinuities were more prominent over the workings (both current and old) in thick seams and at a few place stepping was of the order of 2m and more.
   (g) The width of cracks on the surface varied and the maximum observed was over 1000 mm due to extraction of 8m thick seam at a depth of about 70m.
   (h) In general the impact of subsidence on surface topography was very prominent over caved workings at shallow to very shallow depths.
   (i) Subsidence of the order of 600 mm and more caused severe disturbances in sub-surface and underground water regime resulting in loss of water from aquifers and water tables.
   (j) Subsidence with cracks retarded growth of vegetation on the surface due to loss of water from top-soil.
   (k) Subsidence over unapproachable old workings and also over current workings at depths up to about 100m were generally sudden (taking place within a few hours to a few days of initial indications).
   (l) Damage to buildings took place even with subsidences as low as 300-500 mm over workings at a depth of about 300m.
   (m) Waterlogging of central portion of subsided areas was very commonly seen.
   (n) All major cracks over underground workings were generally within extraction perimeter, i.e., the angle of break was inside the goaf.
2. Maximum subsidence over hydraulically sand stowed underground workings in the coalfield was not more than 6.5% of extraction thickness even with multi-lift and multi-seam extractions at depths ranging from about 35 to 400 m. Over caved workings the subsidence varied but was less than 60% of extraction thickness at depths up to about 480 m. Non-settlement of overlying old workings at a few places caused an increased subsidence due to settlement of both the seams. In general the magnitude of subsidence was more over the areas having rock mass disturbed due to previous underground mining activities. The maximum possible subsidence and maximum subsidence for any given width-depth ratio of extraction (Fig. 1) can be computed with the aid of CMRS computer model which uses the following simple expressions.

\[
S_{\text{max}} = 0.5(1+M)(e'.a'.h'.m') \\
S = \frac{S_{\text{max}}}{9}[4+5 \tan(4- \frac{x-x_c}{x_n-x_c})-1.1)]
\]

where \(S_{\text{max}}\) = maximum possible subsidence, \(m, M = \) rock mass factor, 0.4 for predominantly hard sandstones to 1 for totally disturbed rock mass, \(e' = \) extraction percentage factor, 0.95 for longwall and 0.5-0.8 for bord and pillar, \(a' = \) goaf treatment factor, 0.95 for caving and 0.07-0.1 for hydraulic sand stowing, \(m' = \) extraction thickness, \(h' = \) depth factor, 1 for depths up to 250 m, 1.1 for depths from 251 to 400 m and 1.15 for still greater depths, \(S = \) maximum subsidence for a given width-depth ratio \(x, \) \(x_c = \) non-effective width-depth ratio, and \(x_n = \) critical width-depth ratio.

The maximum subsidence, anticipated for the various coal measure thickness in the coalfield, on the basis of 12% coal availability and 50-80% effective extraction is as given below:
It is noted that a maximum subsidence of about 25m can be expected to take place in the coalfield. There are more than 40 coal seams in the coalfield and in most places these seams are being/shall be extracted one after the other. Therefore the surface area in the coalfield can be anticipated to have subsidence in steps as depicted in Fig. 2. The incremental magnitude of the steps and their interval would depend upon the underground mining parameters and time lag between successive extraction of the seams. The programme for the management and utilisation of surface land under these circumstances should have possibilities of intermediate steps for end use corresponding to each step of subsidence.

**FIG. 2 Subsidence in steps due to multi-seam extraction.**

3. Volume of subsidence troughs - Underground mining of coal seams never lands clean sweep of coal from large areas as panel barriers, protection pillars for roadways, shafts, surface properties, etc., stooks, small pillars, etc. in bord and pillar workings, etc. are left underground. This is all the more true in a situation obtaining in the Jharia coalfield which has multiple number of seams in close proximity. In such situations subsidence can be expected to take place in patches and the volume of subsidence
Subsidence management in Jharia coalfield

troughs for successive extraction of seams and thereby the volume of subsidence at each step can be computed by using the following empirical relationship:

\[ v = 0.53 \frac{SV}{m^3} \]  

where \( v \) = volume of subsidence trough, \( m^3 \), \( S \) = maximum subsidence, \( m \), \( V \) = volume of underground, \( m^3 \), and \( m' \) = extraction thickness, \( m \).

4. Subsidence-time relationship - Subsidence over underground coal mining areas continues for some time after extraction is completed. The time lapse for final subsidence depends upon the state of overlying rock mass. About 70-90% of subsidence, over workings with undisturbed rock mass above, takes place immediately after extraction (extraction period) is completed and the remaining 10-30% subsidence takes about 300-500 days. Over disturbed rock mass about 90-95% subsidence takes place during extraction period and remaining 5-10% takes about 50-100 days. The above subsidence-time relationships are illustrated in Fig.3.

Thus, in a situation as obtained in Jharia coalfield subsidence due to extraction of lower seams (in descending order extraction with caving) can be expected to take a maximum of about 100 days to complete after finish of underground extraction.

5. Subsidence impacts - Subsidence movements, i.e., subsidence, slope and strains, in different magnitude have different impacts on surface, sub-surface and underground properties, water regime and surface topography and environment. On the basis of the experience and subsidence observations the author has made a categorisation of subsidence impacts which are incorporated in CMRS subsidence model. For assessing the feasibility of management and utilisation of subsided land in Jharia coalfield it would be necessary to anticipate impacts of subsidence at every step due to extraction of successive seams.
SUBSIDENCE MANAGEMENT - A CONCEPT

Surface land, especially in a thickly populated country like India, is the most precious asset and therefore it should be put to optimum use. Depending upon climate, availability of infrastructure, etc. the subsided land can be used for storage of water, paddy fields, orchards, pastures and housing and other constructions. The author suggests that the following steps be taken for this purpose.

A. Planning stage
1. Prepare up-to-date surface plans of the area (mine leasehold and about 500 m around it) showing surface contours at 1m interval, water courses on the surface, ponds, houses, colonies, villages, townships, etc., railway lines and roads, aerial ropeways, high tension lines, etc. The plans should also depict the land use pattern on the surface. These plans will also be useful in deciding the mining methods to be adapted.
2. Obtain all possible information and plans of previous mine workings in the area under review.
3. Obtain all borehole records for the area under review.
4. From the above information construct plans, for individual seam, showing seam thickness, seam contours, surface configuration etc. so as to ascertain the areas which can be caved and which need be stowed during extraction.
5. Anticipate subsidence movements separately for individual seams and then collectively for successive extraction of the seams.
6. Using the anticipated subsidence and original surface contours probably surface contours and thereby the change in surface topography, as every mining stage and also at the final stage, can be computed.
7. Anticipate impacts of subsidence at every mining stage on underground, sub-surface and surface properties, features and structures. These impacts should be critically assessed for collapse of any overlying workings thereby adding to subsidence and its impacts, disturbances in overlying virgin seams, possibilities of fires in overlying and the working coal seams, possibilities of damage to water bodies and inundation of underground workings, disturbances in top-soil characteristics, nature and magnitude of damage to buildings, structures, railway lines, roads, etc., disturbances in water regime on the surface including water table, etc.

B. End use
On the basis of the above preparations and anticipations at planning stage itself it should be decided that to what purpose the subsided land can be used at different stages during extraction of seams in succession and then after final subsidence. The use of subsided land at various stages would depend upon the extent and magnitude of degradation caused by subsidence, socio-economic requirements of the area, availability of resources, e.g., money, manpower, water, fertilizer, etc.

C. Minimise land damage
The author feels that the most critical subsidence factor causing damage to surface land is development of steep slopes, wide cracks and stepping. If by orienting the underground mining pattern this can be reduced/minimised then the damage can be
reduced to a considerable extent. The following means can be adapted to reduce subsidence.

- By stowing the underground goaves with sand and/or other suitable solids hydraulically.
- By resorting to partial extraction methods.
- By planning underground workings in such a manner that wider subsidence troughs are obtained.

Hydraulic stowing may not be feasible in most situations because it adds to the cost of coal production, it retards the production rate, sufficient quantity of sand and suitable solids are not readily available in and in the vicinity of the coalfields, and stowing is required for extraction of coal seams below surface properties, etc., where caving can not be done. Hence the adaptation of stowing methods is not being suggested for reducing subsidence and its impacts.

In partial extraction methods, with stowing and caving, a large quantity of coal is left insitu which amounts to loss of coal and the probabilities of fires in such conditions become more. Hence, as a rule partial extraction methods should be avoided as far as possible.

Subsidence trough shape control by planning underground extraction can be done in the manner show in Fig. 4. Two methods

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**Fig. 4** Underground extraction planning for subsidence trough shape control.
shown in the figure can be planned, specially in multi-seam mining situations, to reduce development of steep slopes, wide cracks and steepings on the surface and thereby degradation of surface land.

D. Management of subsided land for various end uses - a few suggestions

As stated earlier the subsided land in Jharia coalfield can be used for storage of water, paddy fields, orchards, pastures, housing and other construction, forestry, etc. The most important operation for any end use of land is plugging of cracks. The cracks in general in undisturbed rock mass have been found to appear with strains reaching 4.5-5.0 mm/m level.

Any use of subsided land in coal mining areas is full of danger of underground fires if steps are not taken at proper time. Plugging of cracks is not only important from the point of view of prevention of mine fires but also important from the standpoint of improving water retention capacity of sub-soil and for reducing loss of surface water which finds way to underground workings through cracks (Fig. 5).

In the areas having only one seam cracks due to subsidence are likely to develop only once. But in case of multi-seam mining situations, as in Jharia coalfield, the cracks can be expected

FIG. 5 Seepage of water to underground workings through cracks.

FIG. 6 Widening of cracks due to multi-seam extraction.
to form repeatedly. In case of superimposed workings the cracks formed due to extraction of top seam tend to widen further with addition of new cracks as illustrated in Fig.6. Whether single or multiple seam underground mining, in Jharia coalfield, the cracks formed due to subsidence should be plugged/filed as soon as they are formed and the operation of plugging should continue to the time till then the cracks do not appear and widen further.

Since, most areas in the coalfield have multiple number of coal seams, such a situation is not likely to be obtained in near future, i.e., in next 10-15 years. In these situations it would be advisable to use subsided land in the following manner.

**Pasture land** - Subsided land with or without prospects of further subsidence can be affectively developed as pasture land. Grass and other suitable vegetations can be planted after taking care of cracks developed due to subsidence in the first instance. Later it may be necessary to do re-planting of grass, etc. in the zones affected by the development of cracks due to subsequent subsidences. For such an intermediate use of subsided land it is not necessary to bring the subsided land to original topography. The author feels that it is not at all necessary to do any reclamation work. However, it would be necessary to make arrangements for drainage of water from the subsided areas to be used as pastures.

**Forestry and plantation** - Forestry and plantation has assumed national importance in India due to its various advantages. A large area (about 10 sq.km) of subsided land in Jharia coalfield has been covered in such schemes and all these areas have to undergo further subsidences in future due to extraction of lower seams. It has been observed at a few places that plantations done up to about 2-3 years before subsidences over caved workings were severely affected as almost all the plants over subsided areas dried out. This indicates that for multi-seam mining situations due care is required to be taken for the plants so that they are not affected by subsequent subsidences. Underground extractions can be planned for larger intervals between successive subsidences so as to allow the plants to overcome the effects of each subsidence. And during each active subsidence period care be taken that the cracks are plugged and the plants get water.

For plantation in subsided land also it is not at all necessary to reclaim the subsided land. But due care is necessary in plugging surface cracks due to subsidence. Planting can be done within a few months of first subsidence. The choice of plants and timing of plantation should depend upon local climate and nature of top-soil.

In the TISCO leasehold area in the coalfield about 47,000 plants were planted over 47 acres of subsided land and 29,000 plants over 29 acres of fire area. In these plantation the most surviving species has been popular with a survival rate of 70% and an average daily growth of about 12 mm/day. Under normal circumstances the growth rate of this plant should be about 60 mm/day.

In the situation obtaining in Jharia coalfield it would be advisable to use a suitable mix of grassland and plantation to maintain/restore eco-system. The plants to be chosen for plantation
should also have mixed root system, because the plants with wider spreading root system have top-soil binding capacity and thus may have a tendency to reduce damage to top-soil due to subsidence. This aspect needs a detailed study.

It may take more than 20-25 years for extraction of all the seams from the areas where seams up to No.10 have already been exploited. The plantations can be expected to yield plenty of wood, which could be helpful in rehabilitation of area in and around the coalfield.

Construction of buildings and structures - There are 14 urban and 113 rural settlements in the Jharia coalfield and about 6,143 million tonne of coal is blocked below them. Every year hundreds of small and medium size buildings are being constructed in the coalfield by private citizens as well as nationalised coal mining industry. Most of these constructions are over barriers between goaves, on the goaves, and in the areas where there is practically no extraction and seams are standing on developed pillars. The more the construction in the coalfield the more the quantity of coal blocked below them.

Under the built-up areas it may not be possible to extract all the seams even with partial extraction and stowing methods. The most appropriate step would be to stop all further construction in the coalfield and then progressively shift as many settlements as possible so as to release maximum possible surface area to effectively plan underground extraction for better management of surface area after subsidences.

The author suggests for better management of subsided land and other lands all construction should be planned for the following situations.

- Temporary structures for 5-10 years life with provision to take care of minor subsidences may be built over the areas planned for extraction after the life of the structures.
- Permanent or semi-permanent buildings and structures should be planned over the areas where practically no further subsidence is anticipated in future and where all the seams have been extracted. A time lapse of about 300-500 days be given to allow for consolidation of rock mass after subsidence. While constructing buildings and structures in such areas several precautions may be necessary in making the foundation, superstructure and service facilities.

For construction of the buildings, etc., it may again not be necessary to bring the surface to original level. Depending upon the magnitude of subsidence and resulting surface topography necessary levelling need be done. Once again plugging of cracks due to subsidence is a must.

CONCLUDING REMARKS

The underground coal mining propositions in Jharia coalfield call for a long-term planning of underground mining to affect subsidence without many steeper slopes, wide cracks and stepping. Due to extraction of a large number of seams in succession subsidence and resulting impacts on surface are to take place again and therefore it would be advisable to use the surface area for grass-
land and plantation till all the seams are exhausted and then construction of permanent and semi-permanent buildings and structures should be planned. For the intermediate period wherever necessary temporary constructions for a life of 5-10 years be made such as not to interfere with the underground extraction programme.

There are about 127 settlements in the coalfield blocking more than 6,000 million tonne of coal and every year hundreds of small and medium size constructions are coming up. In order to effect proper exploitation of coal seams and then manage subsided land it would be advisable to stop all further construction in the coalfield and then progressively shift as many settlements as possible.

A maximum subsidnce of about 25m is anticipated to take place in the coalfield and this shall be taking place in steps as the successive seams are extracted. The development of many steep slopes, wide cracks and stepping can be reduced by adapting the mining methodologies suggested.

For any end use of subsided land the most important operation is plugging of cracks developed due to subsidence, specially in situations such as in Jharia coalfield.

It is felt that a long-term planning is necessary for the coalfield and this planning should include anticipation of subsidences and impacts at every stage of mining to decide upon intermediate and ultimate management of subsided land.

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