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Investigating Roof-Fall Incidents and Safety Methods in Indian Underground Coal Mines.

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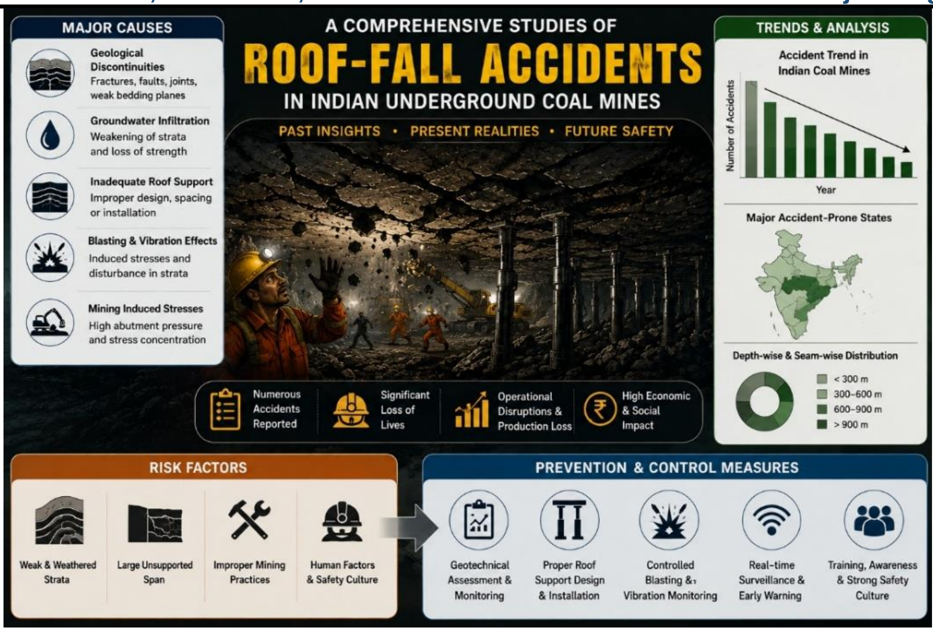
Abstract

Roof fall is one of the most serious and recurring hazards in underground coal mining. It may happen if the roof, coal, sidewalls, or other rock strata become unstable and collapse into an underground working area. Such failures can strike workers and equipment and may result in serious injuries, fatalities, burial, or entrapment. Since underground mining continuously changes the natural condition and stress state of the rock mass, maintaining roof stability is a major challenge for mine management. This paper examines a few underground roof-fall accidents in Indian coal mines between 1952 and 2025, focusing on how the failures occurred, their immediate causes, contributing factors, shortcomings in safety management, and the measures that could have prevented them. It includes West Chirmiri (1968), Kessurgarh (1975), Topa (1982), GDK-8A (2003), VK No. 7 Incline (2006), Prism Coal Mine (2015), and Chhatarpur Mine No. 1 (2025) accidents. The analysis indicates that roof-fall accidents cannot be simply explained by saying that the roof fell. In most cases, the accident is the result of a chain of factors, which includes weak or disturbed geological conditions, changes in ground stress caused by excavation, excessive or newly exposed unsupported roof, inadequate or delayed installation of support, poor workplace examination, unsafe worker exposure, and failure to recognize changing ground conditions. GDK-8A accident exemplifies the need to understand goaf behaviour and stress redistribution during pillar extraction. Similarly, the Prism and Chhatarpur incidents illustrate the serious consequences of allowing workers to remain beneath unsecured or freshly exposed roof areas. Recent DGMS data further show that ground movements continue to be an important safety concern in Indian coal mines. In 2024, ground movement was associated with 6 fatal coal-mine accidents and 8 fatalities, including 2 fatal roof-fall accidents that resulted in 3 deaths. DGMS has also reported that roof and side falls account for approximately 33% of fatal accidents in belowground mining operations. Based on the findings, this paper recommends an integrated approach to roof-fall prevention. It should combine proper geotechnical assessment, controlled excavation, systematic and timely roof support, temporary support where required, continuous monitoring of ground conditions, competent workplace examination, safe operating procedures, effective supervision, and adequate emergency preparedness. Together, they can reduce worker exposure to unstable ground and prevent roof-fall accidents in underground coal mines. [R1]

Keywords

Roof fall; strata control; underground coal mine; roof support; ground movement; pillar extraction; goaf behaviour; DGMS; mine safety; accident prevention.



Graphical Abstract

1. Introduction

Underground coal mine workings tend to disturb the natural stress regime of the rock mass. Once a cut has been made, stress is redistributed with resultant loosening of the immediate roof due to lithology, discontinuities, jointing, bedding, seam geometry, excavation size and shape, mining method, and support. Thus, roof falls are the outcome of geology interacting with the design, development, support and operating practices of the mine. [R2, R9, R10, R11]

The Indian underground coal mining sector has witnessed a number of roof-fall alongside ground control related incidents under both conventional and mechanized mining systems. The cases cited in the background section of this study represent such events occurred in different phases of the industry's development. The West Chirmiri colliery recorded a fall of sides in 1968, while Kessurgarh and Topa collieries registered roof-fall incidents in 1975 and 1982 respectively. GDK-8A witnessed a roof/goaf fall while winning pillars in 2003, VK No. 7 Incline reported a roof fall during continuous miner operation in 2006, while Prism Coal Mine experienced a massive fall of sandstone roof mass during active support operations in 2015. On the other hand, a coal mine at Parasea Colliery recorded falling of stone pieces from sides into the cage/roof canopy in 2024, Orient Colliery Mine witnessed detachment of shaly-coal block from the roof during roof dressing in 2024, Jhiria UG Mine experienced fall of large roof lump while conducting roof dressing in 2024, while Chhatarpur Mine No.1 saw workers walking below freshly exposed and unsupported roof in 2025. [R1, R4, R5, R6, R7]

With the description of the incident, the discussion can be advanced to identify the mechanism of failure. For an academic research work, it is always important to distinguish between the immediate mechanism of injury by distinguishing it from the contributing factors to failure. Thus, the roof fall cases cited in the background section would be discussed using the safety management literature for post-incident analysis in mining industries. The discussion will focus on the event mechanism, immediate causes, contributory conditions, root causes, consequences, and control/barriers. [R9, R10, R11]

2. Problem Statement

The central issue contributing to the safety problem is the exposure of workers to unsafe ground conditions. A roof can give way when a block of rock becomes dislodged; however, the fatality occurs because of the presence of persons in the hazardous zone and the failure of safeguards designed to control, isolate, detect, protect, or warn against such a hazard. As a result, improving support is a necessary measure, but it is not sufficient to the task of improving roof-fall safety. The system must be changed to make ground failure less likely to occur, limit the time and extent of exposure, and warn of impending roof degradation and keep miners out of the hazardous area. [R2, R3, R9, R10]

3. Objectives

- To review major documented roof-fall accidents in Indian underground coal mines. *[R9, R10, R1]*
- To explain the physical and operational mechanisms that lead to roof instability and collapse. *[R9, R10, R1]*

- To distinguish immediate causes, contributing factors and deeper management-system weaknesses. *[R9, R10, R1]*
- To analyses the effect of mining method, pillar extraction, mechanization and freshly exposed roof on accident severity. *[R9, R10, R1]*
- To compare selected roof-fall accidents using fatalities and chronology. *[R9, R10, R1]*
- To examine current DGMS evidence on the continuing importance of ground movement and roof fall. *[R9, R10, R1]*
- To develop practical and research-oriented preventive strategies for reducing roof-fall risk. *[R9, R10, R1]*

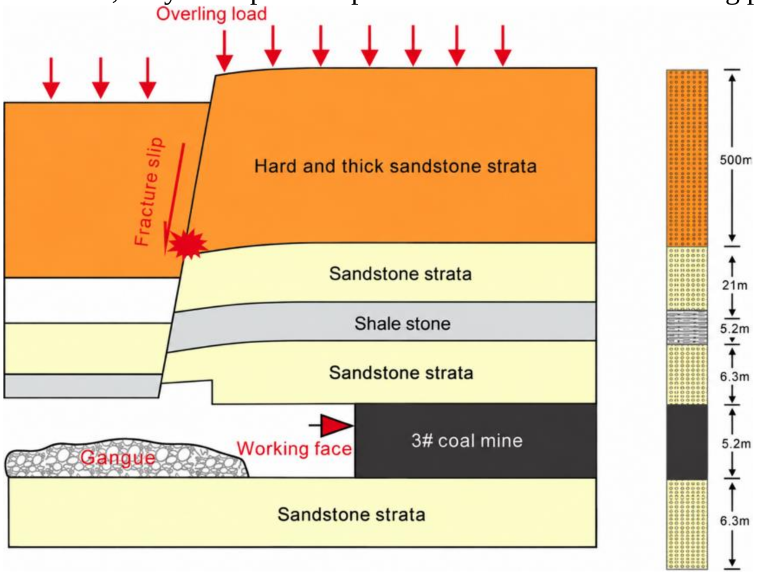
4. Research Methodology

The study utilizes a historical case-study research design. The accident date, location, fatality figures, and causal factors have been sourced from the provided accident compilations. The analysis of the cases is based on underground ground-control and mine-safety principles. The regulatory and statistical data benchmarks have been adopted from the DGMS literature. A distinguishing feature of this paper is that while actual facts of the tested cases have been reported, the analytical extrapolations have been made only for illustrative purposes. Consequently, the contributing factors should not be interpreted as the official findings of a Court of Inquiry. It is also important to note that the present cases are selected on a purposeful basis and not on a comprehensive or census basis. The choice criteria were dictated by the need to identify roof fall, premature collapse, or roof/goaf fall as a causal factor explicitly stated in the accident records. With this caveat, the reader is reminded that the statistical distribution needs to be read only in the context of the selected cases and not as a representative sample of roof-fall accidents in India for the period 1952-2025. [R4, R1]

5. Fundamentals of Roof Stability in Underground Coal Mines

5.1 Geological Factors

Roof behavior is largely determined by the geology of the immediate and main roof. Bedding planes, joints, faults, slips, weak shale or clay bands, fractured sandstone and variable rock strength can all contribute to a reduction in roof competence. A roof mass may well remain stable until excavation relieves lateral restraint or a support element, when a block of roof can suddenly fall away. Given the potential for changes in geology over relatively short distances, roof-support requirements can, therefore, vary from panel to panel or indeed within a working place.[R11,R12,R14]

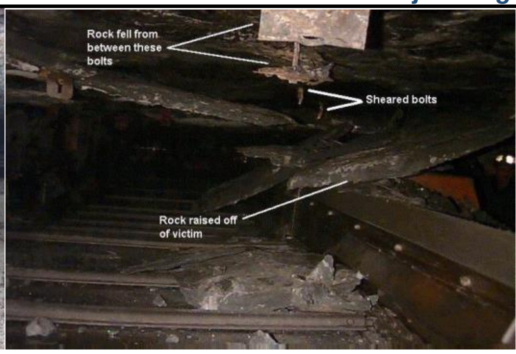


5.2 Excavation and Stress Redistribution

The act of excavation changes the pressure field around the opening. Increasing the span of an excavation or a roof span that is left unsupported may well cause increased load on the roof and the supports. In addition, pillar extraction is particularly important since the removal of coal may cause weighting of the pillars and the convergence of the roof and floor. The GDK-8A case under consideration in the provided records specifically mentions previous falls and signs of weighting and redistribution of pressure before the fatal slip of the roof/goaf. *[R11, R13, R14]*

5.3 Support as a Safety Barrier

Support does not remove weak ground; it is a barrier to its movement. Safe support, therefore, depends on correct design, installation, timing and continuous inspection. Temporary support is especially vital immediately following new roof exposure because this is the time when workers would otherwise be working under unsecured ground. *[R2, R3, R14]*



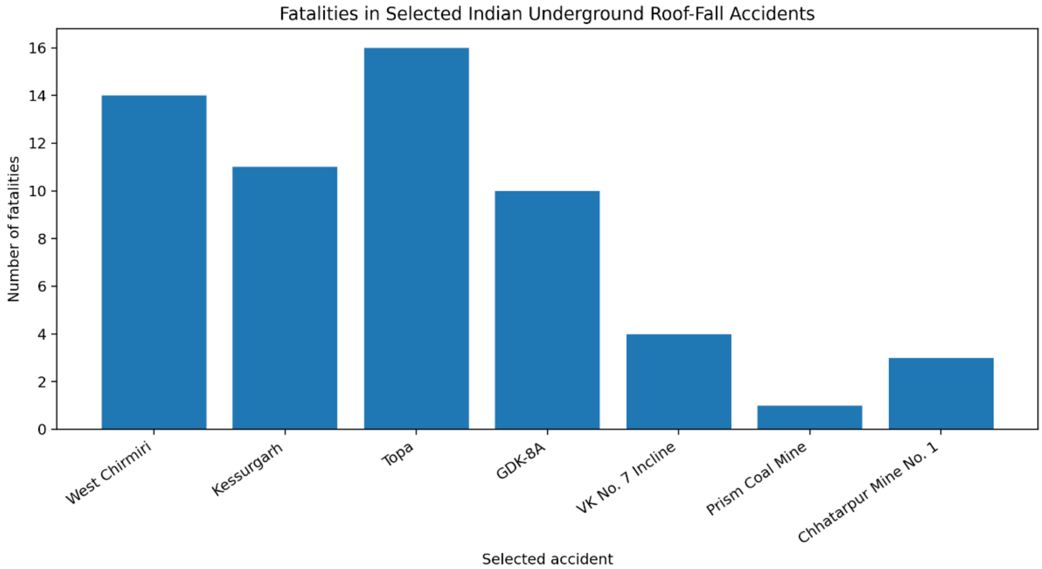
5.4 Worker Exposure

A small roof failure can become a fatal accident if there is a person underneath or at the zone of fall. Thus, exposure becomes a very important variable in fall hazard analysis. Most control measures are aimed at preventing failure or ensuring that there is no one in the maximum fall area before the roof is supported. *[R9, R10]*

6. Major Roof-Fall and Ground-Control Accident Cases in India

Accident	**Year**	**Fatalities**	**Principal mechanism**	**Significance**
West Chirmiri	1968	14	Fall of sides	Fatal ground-control failure; 14 killed and 16 seriously injured [R4]
Kessurgarh	1975	11	Roof fall	Fatal roof-fall exposure [R4, R8]
Topa	1982	16	Roof fall	Roof-fall hazard and need for strata control [R4, R8]
GDK-8A	2003	10	Roof/goaf fall during pillar extraction	Dynamic ground behaviour during pillar extraction [R4, R15]
VK No. 7 Incline	2006	4	Sudden roof fall during continuous-miner operations	Roof fall associated with mechanised face operations [R4, R6]
Prism Coal Mine	2015	1	Large sandstone roof fall during support work	Fatal exposure below a large sandstone block during support work [R5]
Parasea Colliery	2024	1	Collapse of shaft/fall of shaft sides	Stone pieces fell from shaft sides onto protective roofing and cage canopy, fatally injuring a trammer [R1]
Orient Colliery Mine	2024	1	Fall of roof	Shaly-coal block detached during roof dressing and caused fatal injury; death occurred after treatment [R1]
Jhiria UG Mine	2024	2	Fall of roof	Large roof lump detached during roof dressing and fatally injured two workmen [R1]

Chhatarpur Mine No. 1	2025	3	Fall of freshly exposed, unsupported roof	Fatal exposure below freshly exposed, unsupported roof[R7]



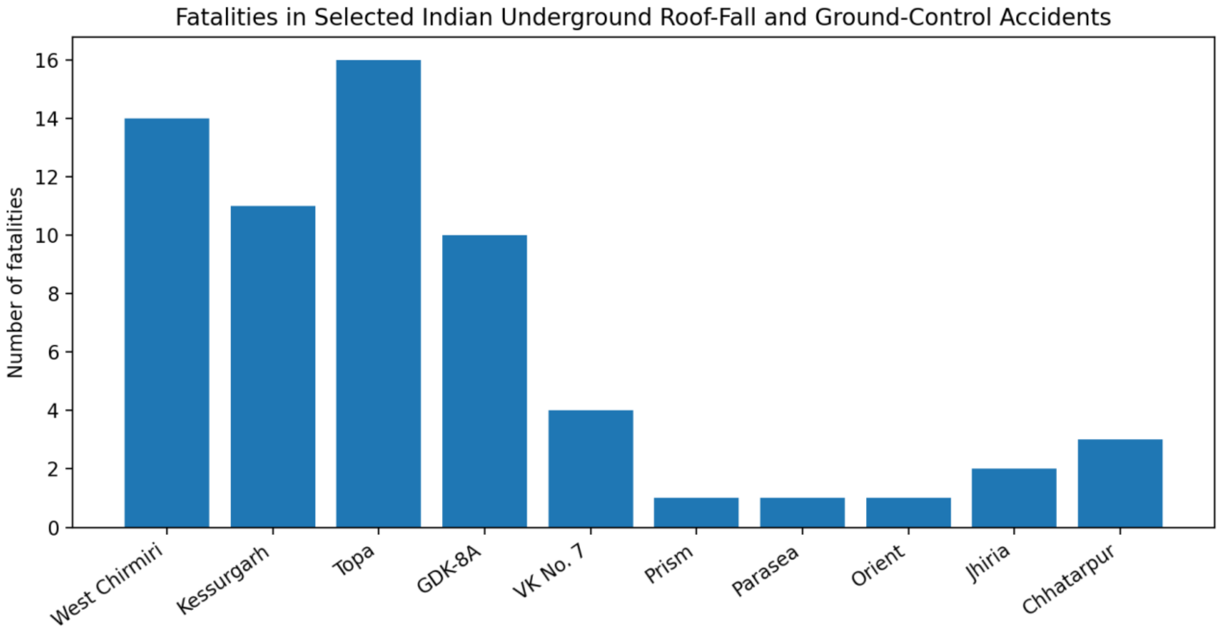


Figure 1. Fatalities in selected Indian underground roof-fall and ground-control accidents. [R1, R4, R5, R6, R7]

7. Detailed Accident Analysis

7.1 West Chirmiri Colliery Accident, 1968

The West Chirmiri Colliery accident happened on 11 April 1968, resulting in 14 miners dead. The official DGMS historical accident table classifies the event as “Fall of Sides” resulting in 16 cases of severe injury. Hence, the present paper should avoid describing the principal mechanism as a “premature collapse of underground workings” unless the original enquiry report is explicitly cited. For analysis, the case may be discussed as the example of fatal ground-control failure; however, the interpretation should be explicitly identified as the authors’ analysis. *[R4]*

7.2 Kessurgarh Colliery Accident, 1975

On 8 th August 1975, Kessurgarh colliery was the scene of an industrial disaster which caused eleven miners to lose their lives and one miner was seriously injured. The root cause of the disaster was the underground roof fall. Thus, the tragedy emphasizes the need for improved strata control measures. Roof falls may occur due to poor geology, faulty excavations, insufficient supports, and improper examination of the roof. The disaster indicates the importance of regular roof examination, adopting suitable support systems, proper excavation, competent supervision, and reducing the exposure of miners to unsafe working conditions. Hence, Kessurgarh disaster is an enlightening event to understand the genesis of strata control hazards, and roof falls in the underground coal mines of India. *[R4, R8]*

7.3 Topa Colliery Accident, 1982

The Topa Colliery accident that happened on 16 th July 1982 resulted in the death of 16 miners due to a roof fall in the mine. The fall of the roof is attributed primarily to the roof fall hazards that are common in underground coal mines. The accident is, therefore, a lesson in understanding the importance of systematic examination of the roof, provision of appropriate roof support, excavation design, and supervision to mitigate ground-control problems associated with underground coal mining in India. The accident is also a reminder of the need to minimize the exposure of miners to an unsupported roof and the need to pay attention to ground conditions as they change constantly. Topa Colliery accident is a crucial case for research into ground control, roof conditions, and the prevention of underground roof-fall accidents in Indian coal mines. *[R4, R8]*

7.4 GDK-8A Colliery Accident, 2003

The GDK-8 A Colliery accident occurred at Godavarikhani No. 8A Colliery, Andhra Pradesh on 17 th October 2003, leading to the death of 10 workers. The main reason for this accident was the fall of roof/goaf during pillar extraction. This occurred when a local fall in the goaf progressed into the working area and crushed the rib, burying the workers. GDK-8A was not the first time GDK Collieries experienced fall related problems as prior falls and indications of strata weighting and stress redistribution had already occurred. GDK-8A is an important case study of strata control, pillar extraction, ground-pressure and prevention of roof and goaf-fall accidents. The accident indicates the relevance of proper depillaring sequence, adequate support, goaf observations, controlled extraction and monitoring of roof weighting and floor heaving. *[R4, R15]*

7.5 VK No. 7 Incline, Kothagudem, 2006

The VK No.7 Incline (Venkatesh Khani No.7 Incline) Accident occurred on 12th November 2006 at 9 A.M. at Kothagudem in Khammam district, Andhra Pradesh, belonging to the Singareni Collieries Company Limited. The accident occurred at 76 Level/23 Dip, Continuous Miner Panel-I, King Seam. A huge portion of the underground stone layer about 3 m thick roof covering the coal face, suddenly got dislodged and brought down the continuous miner, shuttle car, and six workers along with it. Four employees of the SCCL lost their lives, whereas two technical trainers of Joy Mining Machinery who survived the disaster were evacuated with injuries. The workers and the officials of the continuous miner suffered from the mishap. It revealed the hazardous nature of underground coal mining and the risk involved when adopting mechanized continuous miner technology for the first time. As per records, the cause of this accident has been stated to be a roof fall. *[R4, R6]*

7.6 Chhatarpur Mine No. 1 Accident, 2025

The supplied record states that on 6 March 2025 at Continuous Miner Panel E, three mine officials entered under a freshly exposed, unsupported roof. A sandstone layer approximately 6.36 m × 5.5 m and 0.2-0.3 m thick detached from a height of around 2.5 m and killed all three persons. DGMS identified the accident as fall of roof and emphasized the danger of entering or working beneath freshly exposed, unsupported strata. Detachment of the sandstone roof layer. Critical contributing condition: the roof was freshly exposed and unsupported when people were present beneath it. This case is especially important for modern mining because it demonstrates that advanced mechanisation does not remove a basic ground-control principle: personnel must not be exposed to unsupported roof. *[R7]*

7.9 Jhiria UG Mine Accident, 2024

The Jhiria UG Mine accident happened on 4 December 2024, causing two deaths. The DGMS Annual Report 2024 categorizes this incident as fall of roof. Two workmen were engaged in dressing the newly blasted roof at a gallery junction in a depillaring panel. During the activity, one workman fell, and another workman tried to rescue him. Suddenly, a roof lump/stone of size approx 1.4 m × 1.1 m × 0.1 m parted from roof at height of about 3.05 m and fell over the two workmen causing serious bodily injury to them. Both died during treatment at the hospital. The case indicates combined risk of newly blasted roof, dressing of roof, and secondary worker exposure during attempted rescue. [R1]

7.8 Orient Colliery Mine Accident, 2024

The Orient Colliery Mine accident happened on 6 October 2024, turned to be fatal on 27 November 2024. According to DGMS Annual Report 2024, there is a record of one fatality and falls of roof. During the dressing of the roof at the immediate out-bye junction of a development gallery after a blast, a shaly-coal block measuring about 0.9 m × 0.6 m ×

0.15 m, interlocked between 2 roof bolts suddenly fell from a height of about 2.6 m. The block slipped down on the dressing rod and struck the dresser on his chest; he then fell on his back on the blasted coal and sustained serious internal bodily injury. The victim succumbed to the injuries after 52 days of observation in the hospital. This case underlines the danger involved in roof dressing after blasting and the need to control the loose roof properly in advance of and during the exposure of miners. [R1]

7.7 Parasea Colliery Accident, 2024

The Parasea Colliery accident occurred on 10 May 2024. According to the DGMS Annual Report 2024, one worker was killed, and the accident was classified as collapse of shaft/fall of shaft sides. When a trammer was coming out from the cage while pushing an empty coal tub at the pit-bottom of an underground coal mine, stone pieces measuring about 37 cm × 15 cm × 15 cm and 25 cm × 10 cm × 10 cm were fallen from the shaft sides on the protective roofing and cage canopy. The stone pieces were broken into smaller pieces and caused serious injuries to the head and neck of the trammer who expired on the spot due to the injuries. The accident case shows the importance of shaft-side stability to persons working at the pit-bottom. [R1]

8. Comparative Cause Analysis

- Across the cases, the physical event is of a ground failure of some form, but with differing genesis preceding the fall. The 2024 cases add three contemporary examples of ground failures of a particular type – shaft side material fall at Parasea, roof-block detachment during roof dressing at Orient and a large roof lump fall during roof dressing at Jhiria. Six broad causal themes are noted in the cases reviewed. [R1, R9, R10, R11, R13]
- Ground instability: Weak roof, laminated, fractured or otherwise non-integrated roof can lead to slab or block formation and subsequent detachment
- Lack of support: A number of the cases have as a contributing factor the complete lack of support (for ground contact) or inadequate support for the ground contact (roofs) being made.
- Exposure: Where persons were exposed to the roof, either by working in proximity to it, or being underneath it during development or active work on the roof.
- Dynamic ground: Pillar extraction can create dynamic conditions both in terms of ground stress and goaf behaviour, creating additional complexity beyond simple “static” ground failure
- Failure to respond to changing conditions: Weighting/fall of material, weighting of roof, or other ground conditions calling for withdrawal or adjustment should result in such actions being taken. *[R9, R10, R11, R13]*

9. Failure Sequence and Root-Cause Model

For research purposes, the roof-fall accident can be presented as a sequence rather than a simple cause-effect relationship: [R2, R3, R9, R10]

1. There is a geological or stress-related weakness present in the formation. [R2, R3, R9, R10]

2. Mining acts to expose the roof and/or alter the stress regime in the roof. [R2, R3, R9, R10]

3. The exposed roof is either made unstable or requires added support. [R2, R3, R9, R10]

4. Support is absent, deferred, improper, failing or mismatched to need. [R2, R3, R9, R10]

5. Personnel are present in the roof fall hazard zone. [R2, R3, R9, R10]

6. Roof or side material separates itself from the working area or falls. [R2, R3, R9, R10]

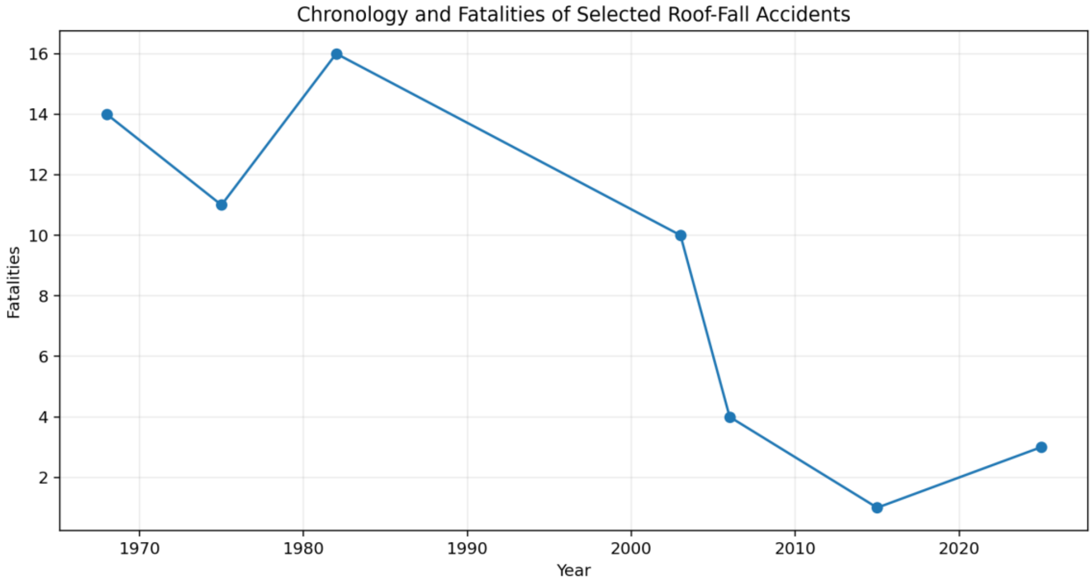
7. Impact, burial, and/or entrapment causes injury or death to personnel. [R2, R3, R9, R10]

8. Secondary effects such as roadway obstruction, equipment damage and restricted rescue are impediments and add to the consequence of the initial roof fall event. [R2, R3, R9, R10]

10. Statistical Interpretation of the Selected Cases

The ten cases selected produced a total of 63 recorded fatalities: West Chirmiri 14, Kessurgarh 11, Topa 16, GDK-8A 10, VK No. 7 Incline 4, Prism Coal Mine 1, Parasea Colliery 1, Orient Colliery Mine 1, Jhiria UG Mine 2, and Chhatarpur Mine No. 1 3. Topa has the highest fatality count in this selected sample with 16. It is important to note that the cases are purposive rather than exhaustive, and therefore this comparison should not be taken as indicative of overall trends in the country. [R1, R4, R5, R6, R7]

The historical cases nevertheless demonstrate that the severity of a roof-fall can vary greatly. A fall may have killed a single person, as in the Prism case, or several workers where a collapse had occurred in an active work area. The severity depends upon the size and behaviour of the failed mass, the location of workers, the extent of unsupported ground, the
mining method and the opportunity for withdrawal. [R5, R7, R9, R10]



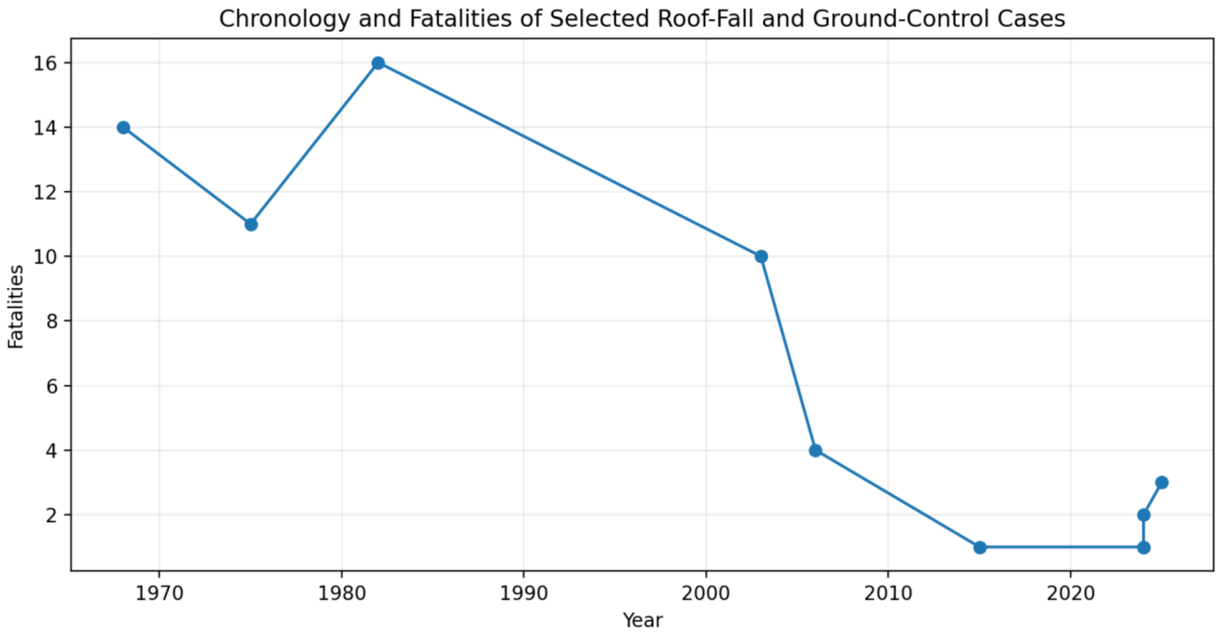


Figure 2. Chronology and fatalities of selected roof-fall and ground-control cases. [R1, R4, R5, R6, R7]

11. Current DGMS Evidence on Ground Movement

DGMS's Annual Report 2024 observes that out of the total 6 fatal accidents resulting in 8 fatalities in coal mines in 2024, ground movement caused 6 fatal accidents, of which 2 were fatal accidents due to fall of roof resulting in 3 fatalities. In the present case series, the two fatal accidents due to roof fall are represented by Orient Colliery Mine and Jhiria UG Mine. The fatality at the Parasea Colliery was, however, reported as a collapse of the shaft/fall of shaft sides. [R1]The present case series thus adds to the evidence that roof fall should not be viewed as an anachronism in the context of newer mechanized mines. Ground movement causes fatal accidents even in the modern era, and the prevention of such accidents requires persistent ground control irrespective of the level of mechanization. [R1, R9, R13]

12. Regulatory and Technical Context

DGMS's official mines-safety legislation portal currently lists the Mines Act, 1952 and the Coal Mines Regulations, 2017 as India's statutory mine-safety laws. [R2]DGMS's circular guidance on reducing roof and side falls includes the installation of strata-control cells, systematic support rules, the use of roof bolting as the primary support method for freshly exposed roof surfaces in development and depillaring districts, a 'no work at face' policy, except for support work, until the roof has been supported to a distance from the face, the use of appropriate roof-bolting machines, and regular risk assessments of roof and side-fall hazards. [R3]These requirements are closely related to the lessons about accidents. They establish a hierarchy in which the roof hazard is evaluated, isolated or supported, and workers are protected before resuming normal operations. [R2, R3]

13. Preventive Measures

13.1 Geological and Geotechnical Assessment

Roof support should be started by studying the ground. That means making a geological map, identifying planes and structural discontinuities, classifying of strata and using local experience to form rules about support. If the roof changes material it is necessary to make a new standard of support instead of continuing mechanically without turning it. [R11, R12, R2]

13.2 Systematic Support

Support should be systematic, timely, and appropriate to the roof category. Temporary support is important during the exposure period. Permanent support should not be used as a substitute for controlling the unsupported exposure period. [R2, R3, R14]

13.3 Immediate Support of Freshly Exposed Roof

The 2015 Prism and 2025 Chhatarpur cases illustrate the need to give special priority to the period immediately following exposure. Work should be organized such that personnel are not required to remain exposed to the risk of unsecured roof in order to install whatever support is necessary to render the area safe. [R5, R7, R3]

13.4 Pillar Extraction and Goaf Control

Pillar extraction shall be carried out by controlled sequence, support plan and a monitoring strategy. Signs of weighting, convergence, cracking, falls or unusual ground behaviour shall be considered as decision points for reconsideration and withdrawal. [R2, R3, R13]

13.5 Mechanized Mining

Continuous miners and other systems should work within a cutting-support cycle in order to limit the exposure of newly exposed roof to personnel. Mechanisation can provide an increase in productivity, but at the same time, expose more ground to hazards more quickly. Equipment placement and support installation therefore need to be timed so that personnel are not working close to unstable newly exposed roof. [R3, R6, R7]

13.6 Examination and Supervision

Roof and sides must be inspected before work and following changes in ground condition. Quality of inspection is more important than merely having an inspection record. Warning signs must have specific escalation rules to ensure that any non-normal observations are acted upon. [R2, R3, R9]

13.7 Monitoring and Early Warning

Convergence measurements, support monitoring and appropriate geotechnical instruments can contribute to indicate changes in ground conditions. Monitoring should be related to specific criteria to response and not be used as a general reporting tool. [R3, R13]

13.8 Training and Competence

Workers and supervisors must receive training in recognizing loose roof, cracks, slips, weighting, damage to supports and unsafe exposure. This training should be updated when a change occurs in the mining method, support technology or local geology. [R2, R3, R9]

13.9 Emergency Preparedness

Even with good prevention a major fall can cause roadway blockage or isolation of personnel. Contingency planning should include procedures for communication breakdown, roadway blocking, personnel injury or self-rescue, and safe withdrawal of rescue teams. Self-rescue and rescue should be compatible with ground-control hazards. [R2, R10]

14. Risk Assessment Approach

A roof-fall risk assessment should be made by considering the possible ground failure likelihood, the number of people exposed to the risk, and the potential size of the fall. The following questions are relevant to a roof-fall risk assessment [R2, R3, R10, R13]:

- Is the immediate roof stable and properly supported? [R2, R3, R10, R13]
- Has the excavation width or span of unsupported openings been changed? [R2, R3, R10, R13]
- Have any cracks, slips, separations, weighting, convergences, or small falls occurred? [R2, R3, R10, R13]
- Has the mining method been changed, or has the pillar extraction caused stress changes? [R2, R3, R10, R13]
- Do workers need to work under or near the newly exposed roof? [R2, R3, R10, R13]
- Can supports be positioned at a distance or on time before exposing the roof? [R2, R3, R10, R13]
- Are there precise criteria for withdrawal in response to ground conditions deterioration? [R2, R3, R10, R13]

15. Research Findings

- Roof fall should be considered as a coupled geology excavation support exposure problem rather than a single rock failure. [R1, R2, R3, R9, R13]
- Freshly exposed unsupported roof is a particularly critical condition because of the possibility for the worker to fall into the hazard zone prior to support establishment. [R1, R2, R3, R9, R13]
- Pillar extraction creates dynamic ground behaviour and therefore needs additional attention to goaf movements/stress redistribution. [R1, R2, R3, R9, R13]
- Mechanisation does not eliminate roof-fall risk but changes the rate of exposure and the relationship between face advance, equipment and support. [R1, R2, R3, R9, R13]
- Historical accident investigations do not always have sufficient evidence to distinguish a particular personal or equipment error. Academic analysis should distinguish confirmed facts and plausible contributing mechanisms. [R1, R2, R3, R9, R13]
- Current DGMS statistics demonstrate that ground movement and roof/side falls are still relevant sources of fatality in modern underground coal mining. [R1, R2, R3, R9, R13]

16. Recommendations

- Develop and periodically update district-specific strata-control plans incorporating current geological and geotechnical observations. [R2, R3, R9, R13]
- Improve practices for immediate temporary support of freshly exposed roof and exclusion from unsupported ground. [R2, R3, R9, R13]
- Establish withdrawal criteria for abnormal roof behaviour, weighting, convergence or repeated small falls. [R2, R3, R9, R13]
- Integrate pillar-extraction design with monitoring of goaf behaviour and stress redistribution. [R2, R3, R9, R13]
- Use support equipment and mechanised roof-bolting systems which reduce worker exposure during support installation. [R2, R3, R9, R13]
- Audit actual roof-support practice in the field, not only compliance on paper. [R2, R3, R9, R13]
- Create a database of roof-fall precursors and near misses and use it as a leading-indicator system. [R2, R3, R9, R13]
- Ensure that changes in mining method, equipment or support design trigger formal risk reassessment. [R2, R3, R9, R13]

17. Conclusion

Roof-fall accidents are one of the most frequent high-consequence risks in Indian underground coal mines. The historical case studies presented in this paper show that the physical event may be a local slab fall, a sudden roof collapse, a goaf-related failure or a large sandstone detachment, but the fatal outcome is strongly affected by whether the workers are exposed to the ground prior to it being made safe. [R1, R2, R3, R4, R5, R7, R9, R13]

The principal factors involved in the cases are adverse geological conditions, stress redistribution, excavation geometry, inadequate or delayed support, unstable shaft sides, freshly exposed or blasted roof, roof-dressing exposure, poor response to warning signs and continued human exposure to unsafe ground. The 2024 Orient and Jhiria accidents demonstrate the risk during roof dressing, while Parasea demonstrates the importance of shaft-side stability and protection at pit-bottom. GDK-8A demonstrates the importance of dynamic ground behaviour during pillar extraction, while Chhatarpur demonstrates the immediate danger of working beneath unsecured or freshly exposed roof. [R1, R2, R3, R4, R5, R7, R9, R13]

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