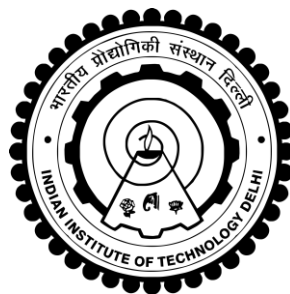


**DESIGNING AND DEVELOPING A
PROP FOR ABUTMENT DEFORMATION MEASUREMENT
(PADM) DURING DEPILLARING PROCESS IN
BORD AND PILLAR MINING**

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**DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
OCTOBER 2021**

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(PADM) DURING DEPILLARING PROCESS IN
BORD AND PILLAR MINING**

by

DHARMENDRA LOHAR

Department of Civil Engineering

Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the



**INDIAN INSTITUTE OF TECHNOLOGY DELHI
OCTOBER 2021**

Dedicated to My Family, Guides and Friends.

CERTIFICATE

This is to certify that the thesis entitled "**DESIGNING AND DEVELOPING A PROP FOR ABUTMENT DEFORMATION MEASUREMENT (PADM) DURING DEPILLARING PROCESS IN BORD AND PILLAR MINING**" submitted by **MR. DHARMENDRA LOHAR** to the Indian Institute of Technology Delhi, is a record of the bonafide research work carried out by him under our supervision and guidance. This thesis work, in our opinion, has reached the standard, fulfilling the requirements for **DOCTOR OF PHILOSOPHY** degree. The research report and the results presented in this thesis have not been submitted, in part or full, to any other university or institute, for the award of any degree or diploma.

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(Dharmendra Lohar)

ABSTRACT

In India, about 98% of underground output of coal is obtained by bord and pillar method and remaining by longwall method. In India, around 70% of total coal reserve now available is amenable for extraction by underground coal mining methods. Therefore, the coal mining industry in the country is gearing up to strengthen underground coal production. Bord and Pillar Mining is a unique challenging branch of engineering. The primary objective is extraction of coal with rock failure whereas if rock fails – it is a problem; and if not – it is a major problem. Extensive research after coal brook colliery disaster of South Africa in January 1960 made underground coal mines a lot safer. Even then, a much debate persists regarding efficacy and quantification of safety with the bord and pillar mining. The most troublesome part is depillaring operations where small remnant pillars are left for short-term stability. Smaller remnant pillars fail early and rapidly transfer the load in working area making depillaring unsafe. Bigger remnant pillars delays failure of roof rock in goaf which may cause large scale cascading failure and invariably results into permanent loss of finite coal reserves. There is no acceptable technology which can measure the deformation behaviour of the remnant pillars and / or roof rock of goaf area. This dissertation is aimed to develop a suitable technology to improve the safety and productivity of depillaring operations of underground coal mining, by designing and developing an instrument for measuring the deformation of goaf area and providing early warning about roof failure.

Several researchers and the workplace environment of depillaring operations indicate for deformation measurement as sole indicator to characterise the behaviour of remnant pillars or the goaf area. A prop for abutment deformation measurement (Acronym as PADM) is designed and developed through the research work undertaken for this dissertation. A holistic approach is undertaken for development of PADM which involves

a critical analysis of the reported field evidences, physical conceptualisation and development of PADM, field behaviour analysis of PADM and substantiation with numerical modelling of depillaring operations of the case study.

PADM is a very low stiffness telescopic prop which measures convergence between roof and floor in the goaf area. The convergence observations are conveyed in tell-tale manner with suitable colour coded warning indicators with three distinct risk levels. Electronic recorder version of PADM has also been developed which records, communicates, stores and analyse convergence data using self-healing wireless communication protocol of mesh networking.

The development of PADM has also been verified with a field application of depillaring panels of an underground coal. PADM observations are compared with indicator props and auto-warning tell-tale (AWTT). Reliability of PADM observations are found superior than prevalent observational techniques. PADM consistently observed that a convergence of at least 100 mm is required before a fall to take place in goaf area at the selected coal mine.

Numerical analysis is also carried out for predicting the goaf area deformation during depillaring operations of the field case study. Major input parameters for the numerical analysis are obtained using field and laboratory testing. The predicted deformation values are compared with the measured values of PADMs. The numerical analysis also substantiated the fact that a deformation of at least 100 mm reached before the failure of remnant pillars in goaf area, as observed by field measurements.

सारांश

भारत में कोयले का भूमिगत खदानों से उत्पादन का लगभग 98 प्रतिशत बोर्ड एंड पिलर मेथड से एवं शेष लोंगवाल माइनिंग मेथड से होता है। साथ ही भारत में लगभग 70 प्रतिशत कोयले के भंडार का खनन केवल भूमिगत खदानों से ही संभव है। इस कारण से भारतीय कोयला खनन उद्योग अपनी भूमिगत खनन उत्पादन तकनीक और प्रणाली को सुदृढ़ करने में लग गया है। बोर्ड एंड पिलर मेथड भूमिगत खदानों से कोयला उत्पादन की एक विशिष्ट प्रणाली है। इस तकनीकी प्रणाली की चुनौतियाँ भी विशिष्ट हैं। कोयले के उत्पादन का मूल उद्देश्य चट्टानों को निर्दिष्ट तरीके से विघटन है। लेकिन भूमिगत कोयला खदानों में निर्दिष्ट तरीके से चट्टानों का विघटन भी एक समस्या है तो विघटन नहीं होना उससे बड़ी समस्याओं का निमंत्रण है।

दक्षिण अफ्रीका की भूमिगत खदान कोलब्रुक कोलियरी की वर्ष 1960 की भीषण दुर्घटना के बाद भूमिगत कोयला खदानों में काम करना अपेक्षाकृत आसान हुआ है। यद्यपि, बोर्ड एंड पिलर मेथड की दक्षता और सुरक्षा के उचित स्तर के आंकलन के सम्बन्ध में विशेषज्ञों के मध्य विवाद है। इस प्रणाली के साथ सबसे चुनौतीपूर्ण भाग डीपिल्लरिंग हैं जिसमें अल्प समय की सुरक्षा के लिए छोटे अवशेष स्तंभों को बनाये रखना जरूरी होता है। इन छोटे स्तंभों का आकर जरूरत से कम होने पर वे समय से पूर्व टूट सकते हैं और इस कारण छत का दबाव ज्यादा क्षेत्र में प्रसारित हो सम्पूर्ण कार्यक्षेत्र की सुरक्षा को प्रभावित कर सकता है। इन छोटे अवशेष स्तंभों का आकर जरूरत से ज्यादा रहने पर ये देर से विरूपित होते हैं और यह देरी एक बड़े कार्यक्षेत्र के विघटन एवं अन्य दुर्घटनाओं का कारक हो सकता है। गोफ एरिया में अवस्थित इन छोटे अवशेष स्तंभों के विरूपण को मापने की अभी तक कोई विश्वसनीय प्रणाली/ तकनीक विकसित नहीं हुई है। इस शोध कार्य का मुख्य उद्देश्य गोफ एरिया में अवस्थित इन छोटे स्तंभों के विरूपण, विरूपण की दर एवं त्वरण को मापने, माप को संग्रहण करने एवं माप को परख कर बिना विलम्ब के कार्य क्षेत्र में सुरक्षा की जानकारी देने वाले एक तकनीकी उपकरण एवं तकनीक का निर्माण करना है जिससे डीपिल्लरिंग के दौरान सुरक्षा और उत्पादकता का स्तर उच्च किया जा सके।

डीपिल्लरिंग के कार्यस्थल का वातावरण इस तरह से होता है कि इन छोटे स्तंभों के विरूपण को मापना ही सुरक्षा प्रणाली और उत्पादकता को उच्च करने का एकमात्र संकेतक

हो सकता है। ऐसा अनेकों शोधार्थियों ने यह इंगित किया है। डीपिल्लरिंग एवं गोफ एरिया की सीमा पर विरूपण मापने के लिए एक अवलंब की संकल्पना, युक्ति, निर्माण एवं प्रयोग इस शोध कार्य के अंतर्गत किया गया है। इस अवलंब का नाम पद्म रखा गया है। पद्म के विकास के लिए एक समग्र द्रष्टिकोण को आधार बनाया गया है और इसके अन्तरगत उपलब्ध प्रकाशित शोध सामग्री का विवेचनात्मक अध्ययन, पद्म की संकल्पना और निर्माण, पद्म को कार्यक्षेत्र में व्यवहार की जांच और पद्म के सिद्धांत का नुमेरिकल मॉडलिंग से अध्ययन भी शामिल है।

पद्म एक बहुत कम कठोरता लिए लम्बाई में भिन्नता को समायोजित करने वाला अवलंब है जो कि कोयला खदान के डीपिल्लरिंग के दौरान छत और फर्श के बीच के झुकाव में बदलाव और विरूपण को गोफ एरिया की सीमा पर मापने के लिए बनाया गया है। इस झुकाव और विरूपण की जानकारी विशिष्ट रंग पट्टिकाओं द्वारा एक सुरक्षित दूरी से ही प्राप्त की जा सकती है। पद्म का इलेक्ट्रॉनिक स्वरूप इसी जानकारी को मापता है, संग्रह करता है, बेतार प्रणाली से संचार करता है और जरूरत पड़ने पर बिना विलम्ब के कार्यक्षेत्र पर ध्वनी और रौशनी के माध्यम से चेतावनी भी जारी करता है।

पद्म के निर्माण एवं संकल्पना को भूमिगत खदान में प्रयोग से भी आंकलन कर सिद्ध किया गया है। इस तरह से प्राप्त जानकारी का संकेतिक अवलंब एवं ऑटो-वार्निंग टेल-टेल से तुलनात्मक अध्ययन भी किया गया है। पद्म की जानकारी को इन अध्ययनों में ज्यादा विश्वसनीय पाया गया। ऐसा पाया गया कि डीपिल्लरिंग के दौरान छत को गिरने या छोटे स्तंभों के विघटन के लिए कम से कम 100 मिलीमीटर विरूपण की ज़रूरत होती है और पद्म ही एकमात्र ऐसा यंत्र है जो इसको विश्वसनीय रूप से मापने में सक्षम है।

जिस भूमिगत खदान में पद्म का प्रयोग हुआ उसका नुमेरिकल एनालिसिस से गोफ एरिया के विरूपण का अध्ययन भी किया गया। इस अध्ययन के लिए आगत परिमाणों को कार्यक्षेत्र एवं प्रयोगशाला में की गयी जांचों से प्राप्त किया गया। नुमेरिकल एनालिसिस से विरूपण के पूर्वानुमान और पद्म द्वारा प्राप्त विरूपण मात्रा का तुलनात्मक अध्ययन किया गया। नुमेरिकल एनालिसिस ने भी इस बात को सिद्ध किया कि गोफ एरिया में अवस्थित छोटे स्तंभों को विघटन के लिए कम से कम 100 मिलीमीटर का विरूपण आवश्यक है।

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(Medium grained sandstone)

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