APPLICATION OF SCHMIDT REBOUND NUMBER FOR ESTIMATING COAL STRENGTH

Prasanjit Dandapat

Department of Mining Engineering
National Institute of Technology Rourkela

APPLICATION OF SCHMIDT REBOUND NUMBER FOR ESTIMATING COAL STRENGTH

Dissertation submitted in partial fulfillment of the

requirements of the degree of

Bachelor of Technology

in

Mining Engineering

by

Prasanjit Dandapat

Roll Number: 112MN0428

based on research carried out

under the supervision of

Prof. M. K. Mishra

Department of Mining Engineering

National Institute of Technology Rourkela

May, 2016

Mining Engineering
National Institute of Technology Rourkela

May 2016

Certificate of Examination

Roll Number: 112MN0428
Name: Prasanjit Dandapat

Title of Dissertation: Application of Schmidt rebound number for estimating coal strength

I the below signed, after checking the dissertation mentioned above and the official record book (s) of the students, hereby state our approval of the dissertation submitted in partial fulfillment of the requirements of the degree of Bachelor of Technology in Mining Engineering at National Institute of Technology Rourkela. I am satisfied with the volume, quality, correctness, and originality of the work.

Prof. M. K. Mishra
Supervisor

Mining Engineering
National Institute of Technology Rourkela

Dr. M. K. Mishra
Associate Professor

May, 2016

Supervisor's Certificate

This is to certify that the work presented in this dissertation entitled "*Application of Schmidt Rebound number for estimating coal strength*" by "*Prasanjit Dandapat*", Roll Number 112MN0428 is a record of original research carried out by him under my supervision and guidance in partial fulfillment of the requirements of the degree of *Bachelor of Technology* in *Mining Engineering*. Neither this dissertation nor any part of it has been submitted for any degree or diploma to any institute or university in India or abroad.

Prof. M. K. Mishra
Associate Professor

Declaration of Originality

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of merits B.Tech MN (Mining Engineering) studies. All information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and reference all material and results that are not original to this work.

I am fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to us on the basis of the present dissertation.

Name: PRASANJIT DANDAPAT
Roll number: 112MN0428
Thesis Title: Application of Schmidt rebound number for estimating the coal strength

Date:
Signature:

Acknowledgment

I wish to express my significant appreciation and obligation to Prof. M.K. Mishra, Department of Mining Engineering, National Institute of Technology Rourkela for presenting the topic and for his rousing direction, helpful feedback and profitable proposal all through the venture work.

I am also thankful to Mr. Abinash Parida, Mr. P.N. Mallick, Mr. M.M. Sethi and other staffs of Department of Mining Engineering for their assistance and help.

I would also like to express my thankfulness to the authorities of MCL and different coalfields of India for their assistance in collection of coal samples.

May, 2016 *Prasanjit Dandapat*
NIT Rourkela Roll Number: 112MN0428

Abstract

In Rock Mechanics, determination of Unconfined Compressive Strength (UCS) of rock is of prime importance as its role in design and analysis of geotechnical problems is crucial. Though laboratory test is the most direct and easy way for estimating the rock compressive strength but UCS determination in the laboratory would be problematic. The laboratory test needs specimen of correct size and features. Obtaining such sample at a time is too difficult. Hence, there is no comprehensive solution to predict the UCS from Schmidt Rebound number. Researchers have developed several equations to make the process easier.

In this investigation, 6 sites has been selected and Rebound number data are collected and equation has been developed.

Keywords: Schmidt Hammer, UCS, Rebound number, UTM, Point Load Index, Regression Analysis

Contents

List of Figures

A List of tables

Chapter 1

INTRODUCTION

1.1 BACKGROUND

Unconfined Compressive Strength (UCS) of rock is considered as an important parameter in investigation of geotechnical issues, for example, rock blasting and support system. In spite of the fact that laboratory test is the most easy and direct way for evaluating UCS, direct determination of UCS in lab is inefficient and costly. Likewise, in direct technique for UCS determination, having adequate number of top quality rock tests is an essential. In any case, it is not generally easy to separate core samples for testing reason in weathered rocks. Therefore, many of the correlations exist to calculate UCS from different parameters. These relationships frequently relate other rock parameters, for example, tensile strength, point load index and Schmidt rebound number. Taking into consideration all these factor and parameter, Schmidt rebound number have the advantages being easy to obtain and easy to calculate and easy to operate.

To build various design structures in rock, rock mechanics engineer need to know various characteristics properties and behaviour of rock. UCS of rock is an essential parameter in designing such projects such as slope monitoring, stability, excavations and many more mining and civil operations. Testing and measuring such properties in the laboratory is simple in theory but in practical, this is the most costly and time taking tests. This includes for sample collection, sample transportation, core preparation and testing based on the standards. In order to perform these simple tests, special samples, such as cylindrical core need to be prepared and the dimension need to be L/D = 2.5 and diameter 54mm. Preparing such sample is too difficult, costly and time consuming too.

However, preparing such regular shaped samples from weathered rock masses is also not that easy. So, under these circumstances, the application of other efficient and cheap methods to carry out such tasks with greater accuracy and consistency will be important. Therefore, there are many indirect approach to carry out such tests which are simpler, require less preparation and can be carried out more easily to in-situ measurement. Such tests include application of Schmidt hammer, point load index and sound velocity method.

The Schmidt hammer rebound hardness test is a simple and non-destructive test originally developed in 1948 for a quick measurement of UCS, and later was extended to estimate the hardness and strength of rock. The mechanism of operation is simple: a hammer released by a spring, indirectly impacts against the rock surface through a plunger and the rebound distance of the hammer is then read directly from the numerical scale or electronic display ranging from 10 to 100. In other words, the rebound distance of the hammer mass that strikes the rock through the plunger and under the force of a spring, indicates the rebound hardness. Obviously, the harder the surface, the higher the rebound distance.

This test can be used both in the laboratory and in the field. It is well known that the Schmidt hammer has been used worldwide for a quick rock strength assessment due to its portability, ease of use, rapidity, low cost and its non-destructive procedure of application.

During a project work conducted at National Institute of Technology (NIT), Rourkela, Schmidt hardness test was carried out to determine the Uniaxial Compressive Strength (UCS) of coal. My study was on 6 working coal seams from different mines. Working areas includes Upper Lajkura and Lower Lajkura seam of Lajkura mine, seam1, seam2, seam3, seam4 of Ananta OCP. All the mines comes under MCL (Mahanadi Coalfield Limited) area.

1.2 OBJECTIVE

My objective includes the following:

- Literature review – All the basic information regarding Schmidt hammer and its working procedure and uses.
- Data collection – Rebound number values were collected by visiting to the corresponding mining area.
- Interpretation – Graph was plotted between N and UCS
- Analysis – Regression analysis of in-situ data obtained through Schmidt hammer and the actual data.

Chapter 2

Literature Review

2.1 Schmidt Hammer

The Schmidt hammer has been widely used for testing the quality of concrete and rocks. It has been increasingly used worldwide because of its simplicity, rapidity, non-destructiveness and portability. The Schmidt hammer is a light hand-held device which consists of a spring-loaded mass inside a piston that is released when the hammer is pressed orthogonally onto a surface [1]. The rebound height of the mass (R) is recorded on a linear scale and gives an indication of the strength of the material being tested. Schmidt hammer models are designed with different levels of impact energy, but the types L and N are commonly adopted for rock property determinations. The type L has an impact energy of 0.735 Nm which is only one third that of the type N [2]. The results of the tests are given as the rebound height and for the L- and N-type Schmidt hammers respectively.

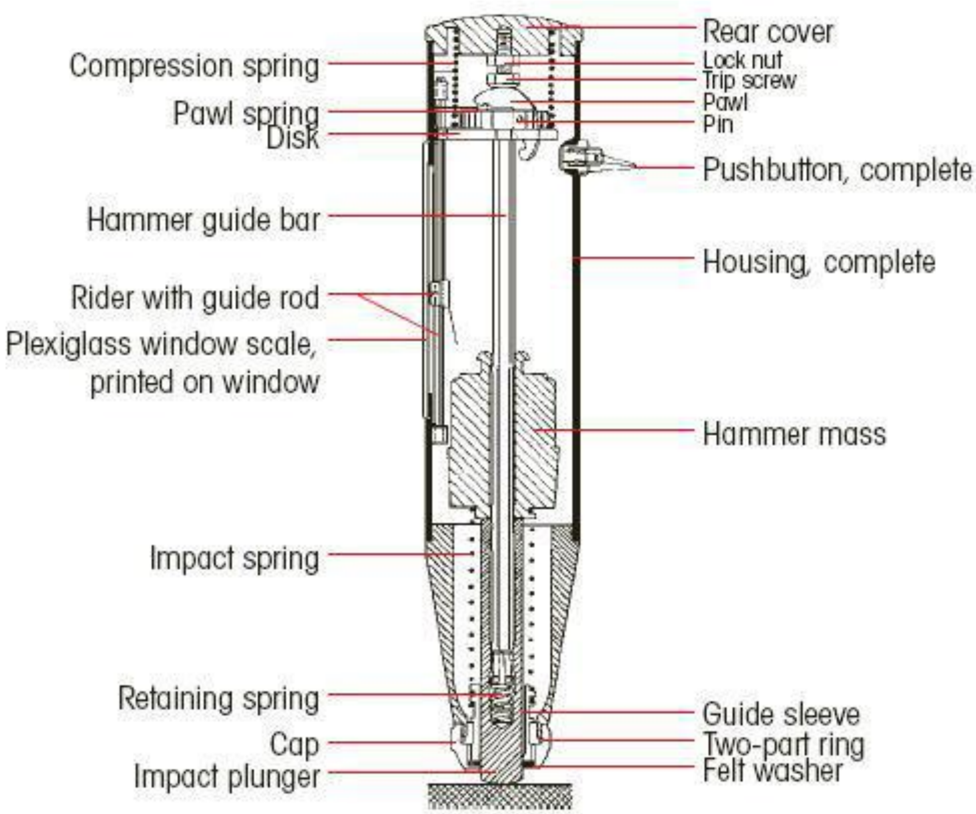

Fig 2.1: Schematic view of a Schmidt Hammer [12]

2.2 Working of Schmidt Hammer

- The device consists of a plunger rod and an internal spring loaded steel hammer and a latching mechanism.
- When the extended plunger rod is pushed against a hard surface, the spring connecting the hammer is stretched and when pushed to an internal limit, the latch is released causing the energy stored in the stretched spring to propel the hammer against the plunger tip.
- The hammer strikes the shoulder of the plunger rod and rebounds a certain distance.
- There is a slide indicator on the outside of the unit that records the distance traveled during the rebound. This indication is known as the rebound number.
- By pressing the button on the side of the unit, the plunger is then locked in the retracted position and the rebound number (R-number) can be read from the graduated scale.
- A higher R-number indicates a greater hardness of the concrete surface.
- The tests can be performed in horizontal, vertically upward, vertically downward or any intermediate angled positions in relation to the surface.

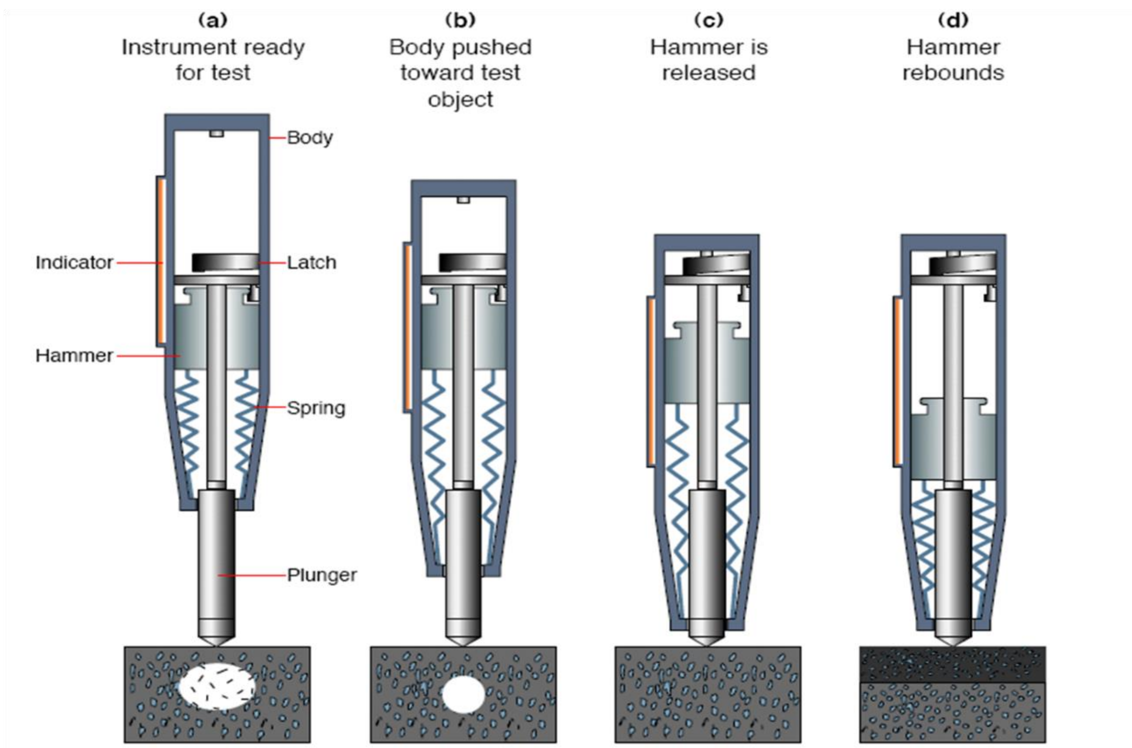

Fig 2.2: Working of Schmidt Hammer [13]

2.3 Compressive Strength

The strength of a material may be broadly defined as the ability of the material to resist imposed forces. If is often measured as the maximum stress the material can sustain under specified loading and boundary conditions. Since an understanding of the behaviour in tension of a material such as rock is of great importance, the tensile strength of that material is normally measured and is used to compare one rock with another. Considering other cases like soil, attention has been directed more towards the measurement and use of the shear strength or shearing resistance than towards any other strength parameter. In the case of concrete, the compressive strength is the most commonly measured strength parameter and this is also true for rock specimens [3].

For the uniaxial or unconfined compressive strength test a right circular cylinder of the material is compressed between the platens of a testing machine as illustrated. The compressive strength is then defined as the maximum load applied to crush the specimen divided by the cross-sectional area. It can be written as follows:

$P = F/A$…………………… (2.1)

Rock strength has been found to be size dependent because of the cracks and fissures that are often present in the material. Rocks with parallel arrangements of minerals or joints have been found to be noticeably anisotropic (different strengths in different directions) [4].

2.4 Tensile Strength

The tensile strength of rock is an important parameter for consideration of properties and behaviour of rock. In contrast a number of direct or indirect tensile strength tests are commonly carried out for rock. In a direct tensile strength test a cylindrical rock specimen is stressed along its axis by means of a tensile force. The tensile strength is then calculated as the failure tensile force divided by the cross-sectional area.

It has been found that a rock core will split along a diameter when loaded on its side in a compression machine. This is the basis of the Brazilian test which is an indirect method of measuring tensile strength. A rock specimen having a disc shape with diameter (d) and thickness (t) is loaded. If the failure load is P then the tensile strength (σ_t) is calculated from

$\sigma_t = 2P/(\pi dt)$…………………… (2.2)

Generally the Brazilian test is found to give a higher tensile strength than that obtained in a direct tension test, probably because of the effect of fissures in the rock. Another method of determining tensile strength indirectly is by means of a flexural test in which a rock beam is failed by bending [5]. Either three point or four point loading may be used in the test. For a cylindrical rock specimen (diameter d) and the four point loading arrangement, it may be shown that the tensile strength (σ_t) is

$\sigma_t = 32\ PL/(3\pi d^3)$…………….. (2.3)

Where, P is the failure load applied. For a beam of rectangular cross section (height h and width w) the tensile strength is

$\sigma_t = 2\ PL/(wh^2)$ ………………. (2.4)

The tensile strength determined from beam bending tests is found to be two to three times the direct tensile strength. The point load strength may be used to provide an indirect measurement of tensile strength, but it is more commonly used as an index test. The point loading is applied to rock core specimens or to irregular rock fragments in a testing machine. If P is the failur load and D is the separation between the platens, the point load strength index (Is) is defined as

$I_S = P/D^2$ ……………………….. (2.5)

Corrections are applied to IS to allow for specimen size and shape to yield the size corrected point load strength index (I_{S50}) which is defined as the value of IS for a diametral test with D equal to 50mm. The value of I_{S50} is about 80% of the direct tensile strength [6].

2.5 Factors Influencing Test Results

Surface Smoothness – The surface roughness significantly hampers the R-number obtained. Tests performed on a rough-textured finish will typically result in crushing of the surface paste, resulting in a lower number [7]. Alternately, tests performed on the smooth texture will typically result in a higher R-number. Therefore, it is recommended that test areas with a rough surface be ground to a uniform smoothness. This can be achieved easily with a Carborundum stone or similar abrasive stone.

Age of Rock – Rock continues to develop strength with age as it solidifies. This is the reason behind the development of data relating rebound numbers to the compressive strength of cores sample [8]. Testing of freshly blasted coal seam less than 3 days old or concrete with expected strengths less than 1000 psi is not recommended [9]. This is because the R-numbers will be too low for an accurate reading.

Calibration of the Rebound Hammer – The device itself should be serviced and verified annually or whenever there is a reason to doubt proper performance. Verification of proper performance of the device includes the use of a test anvil [10]. Impacting the proper test anvil with a properly functioning device will typically result in rebound numbers of 80 ± 2. If the device is believed to not be functioning properly, it is recommended to send it back to the manufacturer or experienced facility for repairs and re-verification.

2.6 ISRM Recommendation

To calculate UCS values using Schmidt rebound number ISRM recommended these parameters [11].

Core dimension	:	NX or larger
Block edge length	:	6m
Range of applying	:	Not considered
Impact number	:	20 impacts on sample, at different points
Calculation	:	Record 20 rebound values from single impacts separated by at least a plunger diameter and average the upper 10 values.

It also recommends a graph shown in Fig 2.1 to follow for quick measurement of UCS from direct impact of Schmidt hammer.

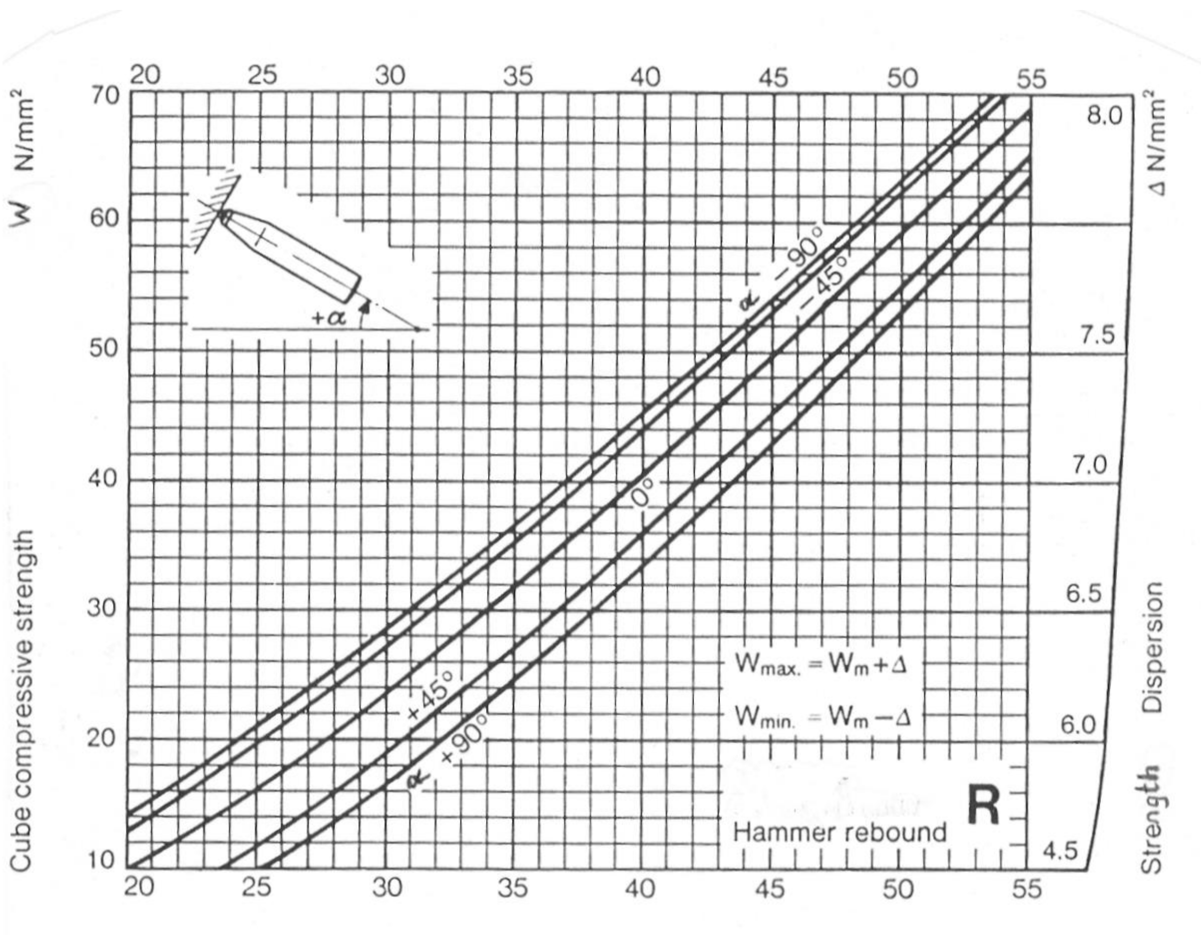

Fig 2.1: Universally accepted graph for quick measurement of UCS [14]

Chapter 3

Experimental Investigation

Different methods can be used in the laboratory to find out the UCS of a rock material. But, in case of in-situ UCS measurement use of Schmidt hammer has gain its popularity because of its simplicity and easy to handle. This project deals with the measurement of Schmidt rebound number both in-situ and laboratory measurement of UCS.

3.1 Experimental Procedure

3.1.1 Procedure for in-situ Measurement

The following procedure has been adopted to get the desired UCS values from in-situ measurement through Schmidt Rebound Hammer –

- Visit to the mine site.
- Selection of area where readings were taken.
- 20cm by 20cm surface area was prepared by peeling the remaining coal and cleaning the area and performing about 20-40 tests on each area.
- Readings were taken from single impacts separated by at least a plunger diameter.
- Precaution has been taken, so that no place must be hit twice.
- To carry out the test, Schmidt hammer was hold perpendicular to the face.
- Then it was pressed, until a hammering sound was heard.
- After hearing the hammering sound, its lever was pressed and Schmidt hammer was released.
- The reading was noted down from the scale provided.
- Again, Schmidt hammer was pressed against a hard surface and the lever was relaxed.
- Among the rebound number obtained, the five smaller values were discarded and the mean value of the rest was considered as the Schmidt number for that point.

3.1.2 Laboratory Method of Measurement

The following procedure has been followed to carry out laboratory measurement of UCS –

- Cubical sample of dimension 12*12 inch has been collected from the above mentioned areas from where rebound number has been taken.
- Sample has been cleaned properly and surface has been smoothened, so that it can be cored properly.
- Then coring has been done using coring machine from the laboratory provided.
- Sample has been cored properly into cylindrical shape having L/D = 2.5 and diameter=54mm.
- Then, cylindrical core was set to calculate UCS using Universal Testing Machine (UTM).

Chapter 4

Data collection, Result and Analysis

My research project was carried out considering 6 different seams from 2 different mines. It includes Lower Lajkura seam and Upper Lajkura seam of Lajkura Mine, Jharsuguda and seam 1-4 of Ananta OCP, Talcher. Both the mines comes under the supervision of Mahanadi Coalfield Limited (MCL). The following data gives us brief ideas about the mine and its working condition.

4.1 Mine visit – Lajkura Mine

4.1.1 Introduction

Lajkura Opencast Project (1Mty) was sanctioned by the Government of India in August 1983 and the production started from 1984-1985. The target of coal production the year 2015-2016 is 30 Lakh tonnes and the target OB is 60 Lakh Cu. mtr. At present Lajkura Opencast Project is running on an extension of (1.01 Mty) which got approval in the year 2002. The life of this mine is up to 2015. Further extension of the mine had been approved for 29 years. Whose land acquisition work is in process. There is a proposal for 4.5 Mty for further expansion for which action has been taken.

- Land acquisition for mining 392.98 Ha is being process.
- For 159.18 Ha forest Land, stege-1 is already approved and stage-II approval is under process.
- 116.056 Ha of non-forest (Govt.) Land has already been acquired and ready for mining.
- Outsourcing proposal for 4.5 Mty has been processed.
- Environmental clearance for 4.5 Mty has been obtained from Ministry of Environment and forest.

4.1.2 Geographical location:

Lajkura opencast project is located in IB Valley coalfields over Orient Colliery leasehold. This project is situated in the District of Jharsuguda and well connected to NH-200. NH-6 and NH-10. Brajrajnagar is the nearest railway station.

4.1.3 Geology:

IB Valley Coalfields form a part of Chhatishgarh Gondwana outlier within the main sone Mahanadi Valley Gondwana Basin. The topography of the block is generally flat baring from hillocks in the extreme dip of the property. The highest altitude above mean sea level is 278 mtrs and the lowest is 232 mtrs in the area.

Lajkura Coal horizon occur in Lajkura II block of IB Valley coalfields. The seam occur in Barakar Karaharbari formation of lower Gondwana. The Overburden of Lajkura OCP is medium hard course grained sand stone with shale bands and clay beds at places. The area is free from any major fault.

4.1.4 Location

South-Eastern part of the coalfield

Latitude	:	21 48’39’ to 21 49’55’N
Longitude	:	83 53’15’ to 83 54’50” E
Toposheet No.	:	64 0/13 (RF 1:50,000)
District	:	Jharsuguda
State	:	Odisha

4.1.5 Mining System

OB removal is done by shovel-dumper combination.

In shovel-dumper combination, Rope shovel, Hyd. Excavators both front-end and Back-hoe in connection with 50Te/ 60Te dumpers are used.

At present Dragline is not in operation.

4.1.6 Coal Production

The coal production is being carried out both by means of Surface miner as well as convention method of drilling, blasting and crushing.

The surface miner is deployed contractually. Cutting/Crushed coal is transported by deploying contractual tipper to the railway sliding No III.

The blasted coal is transported to CHP contractually and after crushing from CHP it is again transported to Rly. Sdg. contractually.

The thickness of coal seam is 18-20 mtrs. Cutting, lading and transportation of coal by deploying Surface miner, Pay Loader and Tipper is being done by Single contractor i.e. M/s. SICAL Logostics Pvt. Ltd.

Mainly 3 machines are used for excavation and handling purpose. Namely D-7 and D-9 having capacity of 4.5M^3, BE-1000(62) having capacity of 5M^3 and HMB 575 having capacity of 5M^3.

4.1.7 Rebound Hammer Number

Surface has been prepared to take the readings of Rebound Number as per standard practice suggested by ISRM and sample was collected to carry out further experimentation in laboratory.

Following are the average Rebound Number values of 3-4 impact points of the test area obtained using Schmidt Rebound Hammer for Upper Lajkura seam and the UCS values were calculated using fig 2.1.

Table 4.1: Rebound number and UCS values for Upper Lajkura seam

Serial number	Rebound number (N)	UCS(kg/cm^2)
1	38	320
2	33	250
3	37	310
4	30	210
5	28	180
6	35	280
7	36	290
8	42	380
9	38	320
10	46	450
11	50	515
12	26	158
13	44	420
14	36	290
15	28	180

The corresponding relationship was plotted between Rebound number values and Compressive strength using table 4.1. The graph shows direct relationship among them.

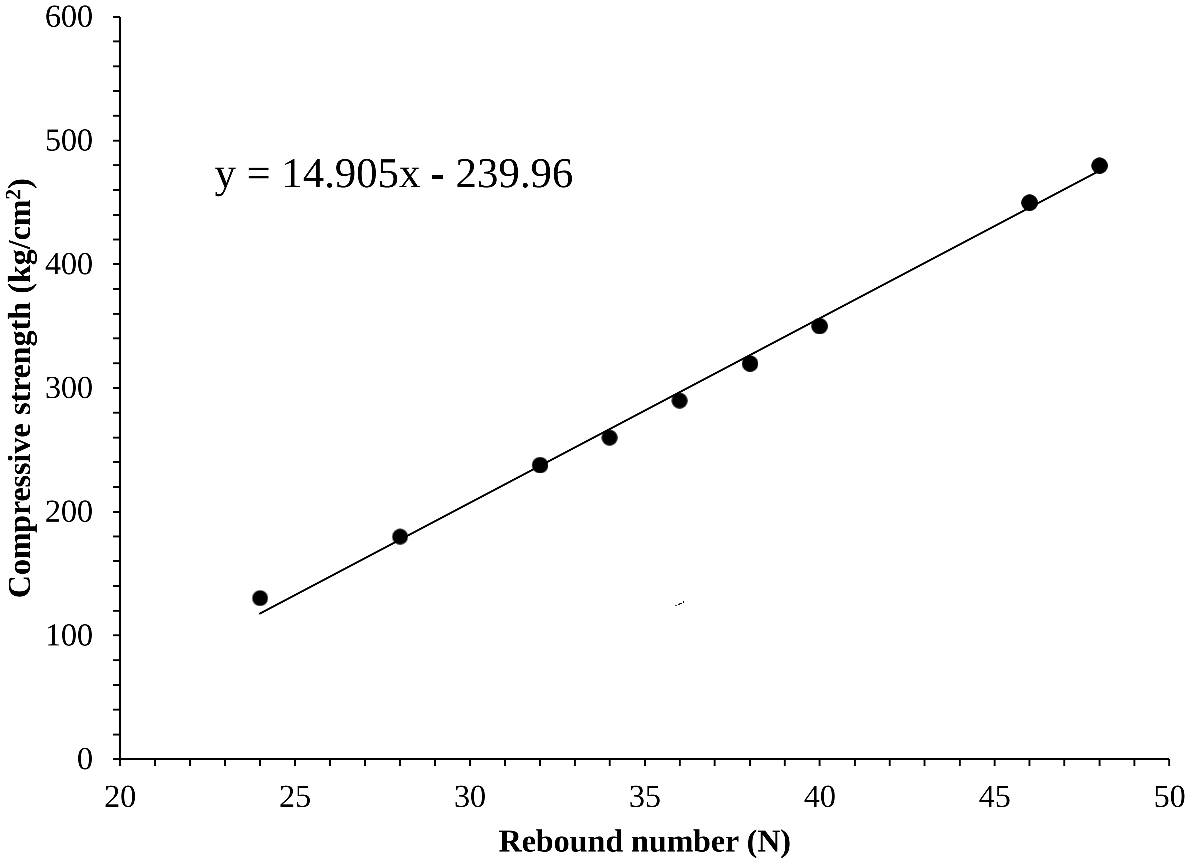

Fig 4.1: Relationship between N and UCS for Upper Lajkura seam

Following are the average Rebound Number values of 3-4 impact points of the test area obtained using Schmidt Rebound Hammer for Lower Lajkura seam and the UCS values were calculated using fig 2.1.

Table 4.2: Rebound number and UCS values for Lower Lajkura seam

Serial number	Rebound number (N)	UCS(kg/cm^2)
1	36	290
2	24	130
3	38	320
4	34	260
5	40	350
6	48	480

7	46	450
8	46	450
9	28	180
10	32	238
11	40	350
12	38	320
13	48	480
14	46	450
15	32	238

Considering table 4.2 following relationship was plotted between Rebound number and Compressive strength values. The graph shows direct relationship among them.

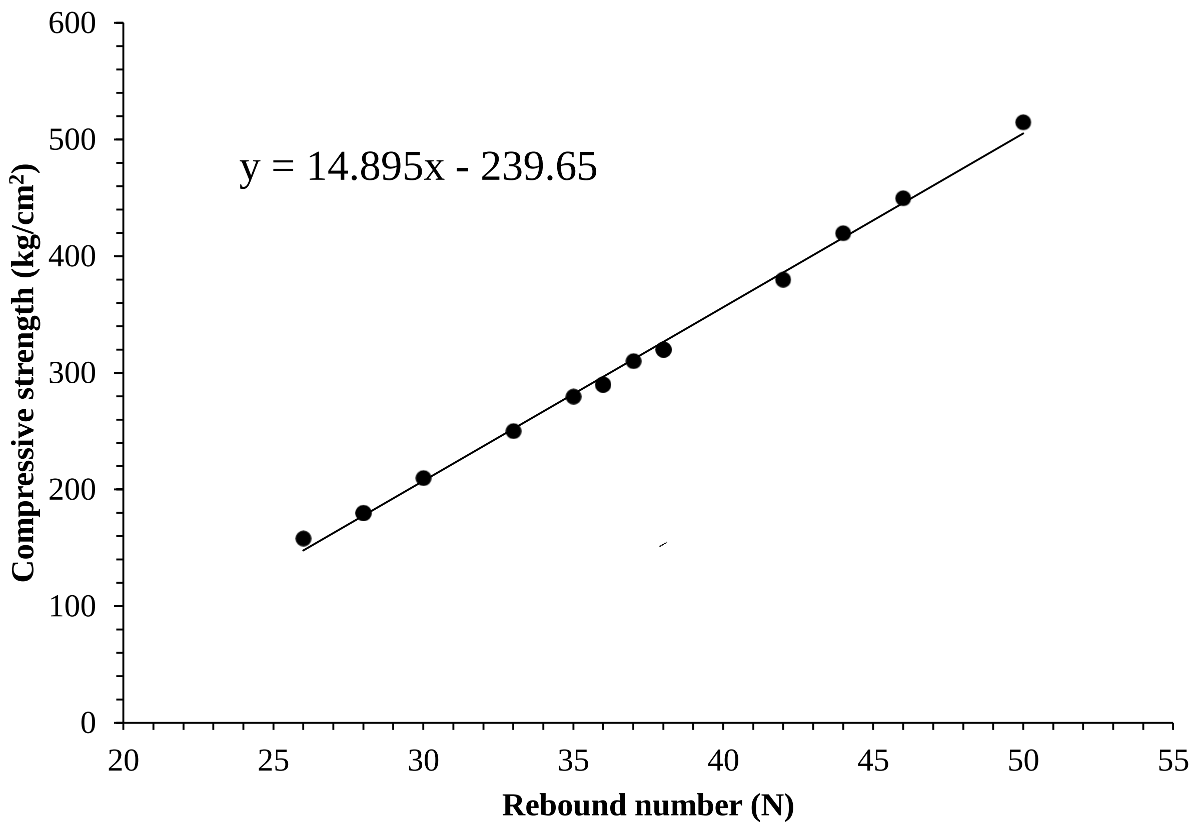

Figure 4.2: Relationship between N and UCS for Lower Lajkura seam

4.2 Mine visit – Ananta OCP, Talcher

4.2.1 Introduction

1. Name of the mine : Ananta OCP
2. Area : Jagannath Area
3. Capacity : 15 Mty
4. Mining Method : Open Cast Mining
5. Geographical location : 20N 57’ 0.3702’’ latitude and 85E 13’ 0.537’’ longitude.

6. Name of the Projects:

These are the list of projects undertaken by Ananta OCP.

Table 4.3: Overall project details of Ananta OCP

Serial No.	Name of the project	Capacity (Mty)	Sanctioned Capital (in crore)	Completed in the year
1	Ananta O/C Expn.	4.00	156.49	03/98
2	Ananta O/C Expn. Ph-I	1.50	46.99	03/97
3	Ananta O/C Expn. Ph-II	6.50	35.88	03/07

7. Ongoing Projects:

Following are the list of projects presently working in Ananta OCP

Table 4.4: Ongoing project details of Ananta OCP

Serial No.	Name of the project	Capacity (Mty)	Sanctioned Capital (in crore)	PR approval date
1	Ananta OCP Expn. Ph-III	3.00	207.28	31.08.2008

8. Details of mine

The construction activities of CHP with SILO loading arrangement at Bharatpur siding and Ananta siding is in progress.

Stage-I Forestry clearance of 224.730 ha Forest land not achieved during 2013-14. 15 MTPA capacity SILO is under construction at Ananta OCP.

9. Connectivity

It is well connected by means of roadways and railways. Its nearby bus stand is Talcher bus stand which is 14.8kms away from it and nearest railway station is Talcher railway station 14kms away from it.

4.2.2 Test Data

Following are the Rebound Number values obtained using Schmidt Rebound Hammer for seam1, Ananta OCP and the UCS values were calculated using figure 2.1.

Table 4.5: Rebound number and UCS values for seam1, Ananta OCP

Serial number	Rebound number (N)	UCS(kg/cm^2)
1	28	180
2	38	320
3	34	260
4	36	290
5	42	380
6	36	290
7	34	260
8	28	180
9	48	480
10	52	550
11	46	450
12	38	320
13	32	238
14	36	290
15	36	290
16	36	290
17	32	238
18	38	320
19	42	380
20	24	130
21	26	158
22	34	260
23	36	280

24	32	238
25	38	320
26	36	290
27	34	260
28	41	370
29	50	515
30	54	580
31	37	310
32	42	380
33	31	220
34	27	165
35	40	350
36	46	430
37	50	515
38	33	250
39	26	140
40	41	370
41	38	320
42	38	320
43	32	238

Considering Table 4.5 following relationship was plotted between Rebound number values and Compressive strength. The graph shows increase in Rebound number, the compressive strength also increases. So the graph 4.3 shows linear trend line among them.

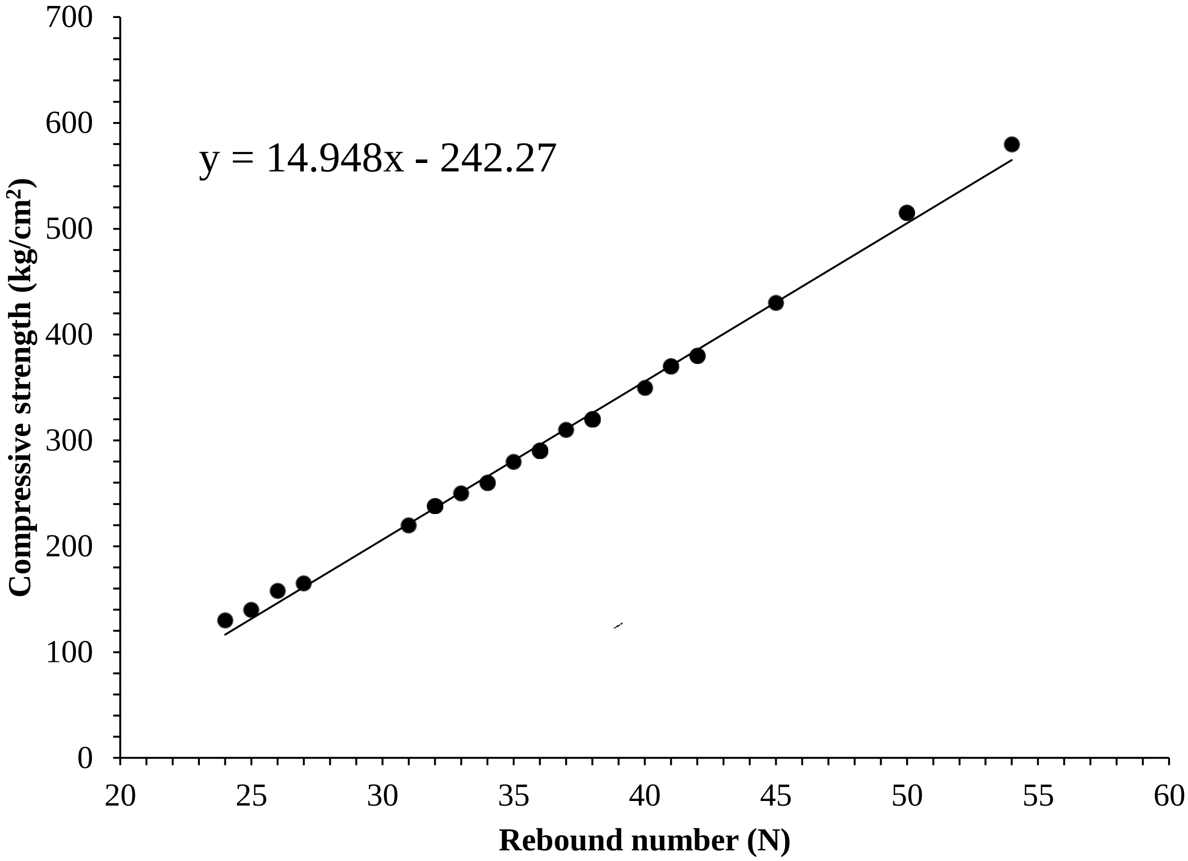

Figure 4.3: Relationship between N and UCS for seam1, Ananta OCP

Following are the Rebound Number values obtained using Schmidt Rebound Hammer for seam2, Ananta OCP and the UCS values were calculated using figure 2.1

Table 4.6: Rebound number and UCS values for seam2, Ananta OCP

Serial number	Rebound number (N)	UCS(kg/cm^2)
1	41	370
2	27	165
3	36	280
4	38	320
5	36	290
6	38	320
7	34	260
8	31	220

9	30	210
10	30	210
11	26	158
12	24	130
13	28	180
14	40	350
15	42	380
16	38	320
17	36	290
18	42	380
19	40	350
20	42	380
21	46	430
22	41	370
23	46	290
24	38	320
25	27	165
26	24	130
27	29	190
28	24	130
29	22	110
30	46	430
31	42	380
32	38	320
33	34	260
34	26	158
35	36	280
36	31	220

Considering table 4.6 following relationship was plotted between Rebound number values and Compressive strength. The graph 4.4 shows linear relationship between Rebound number and Compressive strength.

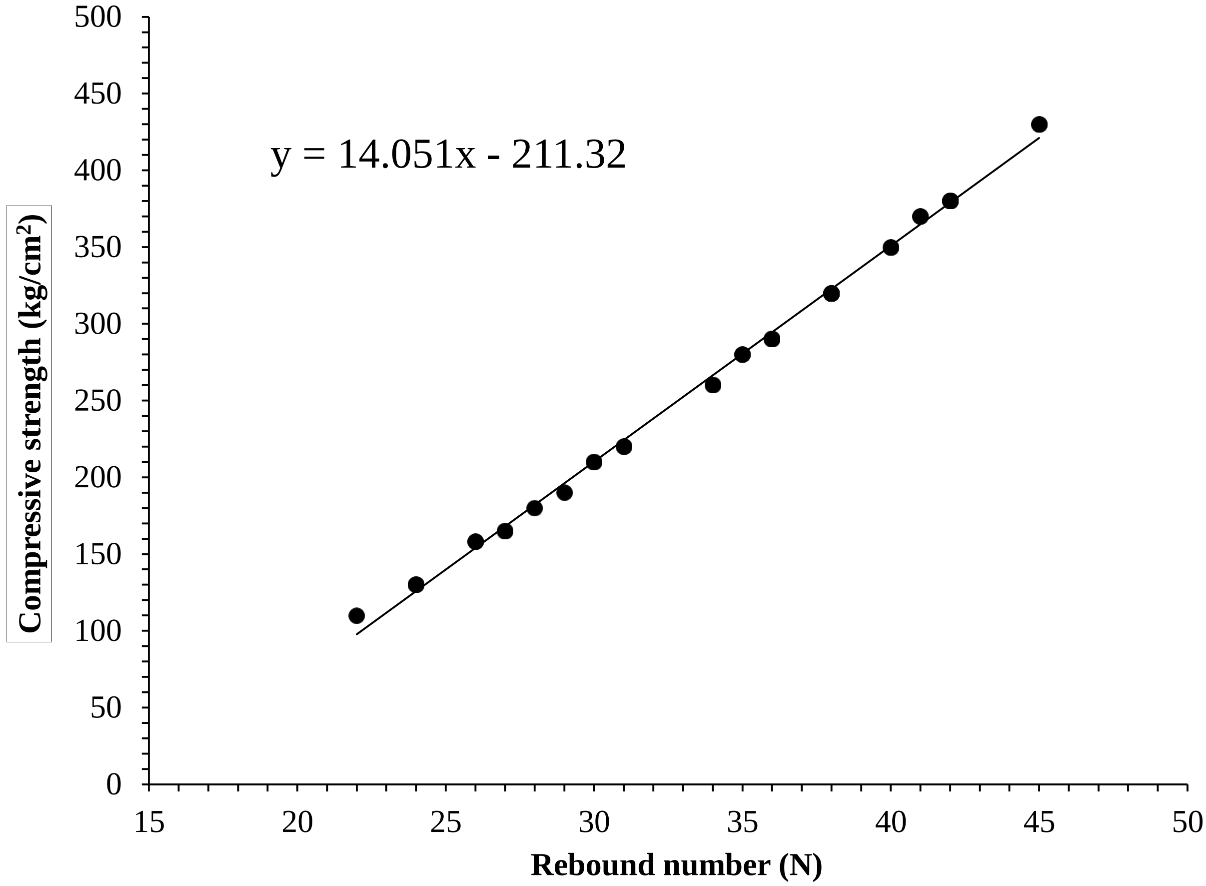

Figure 4.4: Relationship between N and UCS for seam2, Ananta OCP

Following are the Rebound Number values obtained using Schmidt Rebound Hammer for seam3, Ananta OCP and the UCS values were calculated using figure 2.1.

Table 4.7: Rebound number and UCS values for seam3, Ananta OCP

Serial number	Rebound number (N)	UCS(kg/cm^2)
1	37	310
2	38	320
3	42	380
4	31	220
5	22	110
6	28	180
7	46	450

8	42	380
9	40	350
10	38	320
11	35	280
12	22	110
13	24	130
14	60	210
15	42	380
16	36	290
17	34	260
18	37	310
19	29	190
20	50	515
21	35	280
22	22	110
23	36	290
24	42	380
25	48	480
26	35	280
27	31	220
28	42	380
29	40	350
30	36	290
31	33	250
32	34	260
33	25	140
34	38	320
35	37	310
36	32	238
37	48	480
38	36	290
39	35	280

Considering table 4.7 following relationship was plotted between Rebound number values and Compressive strength. The graph 4.5 shows linear increase trend line of compressive strength with respect to rebound number.

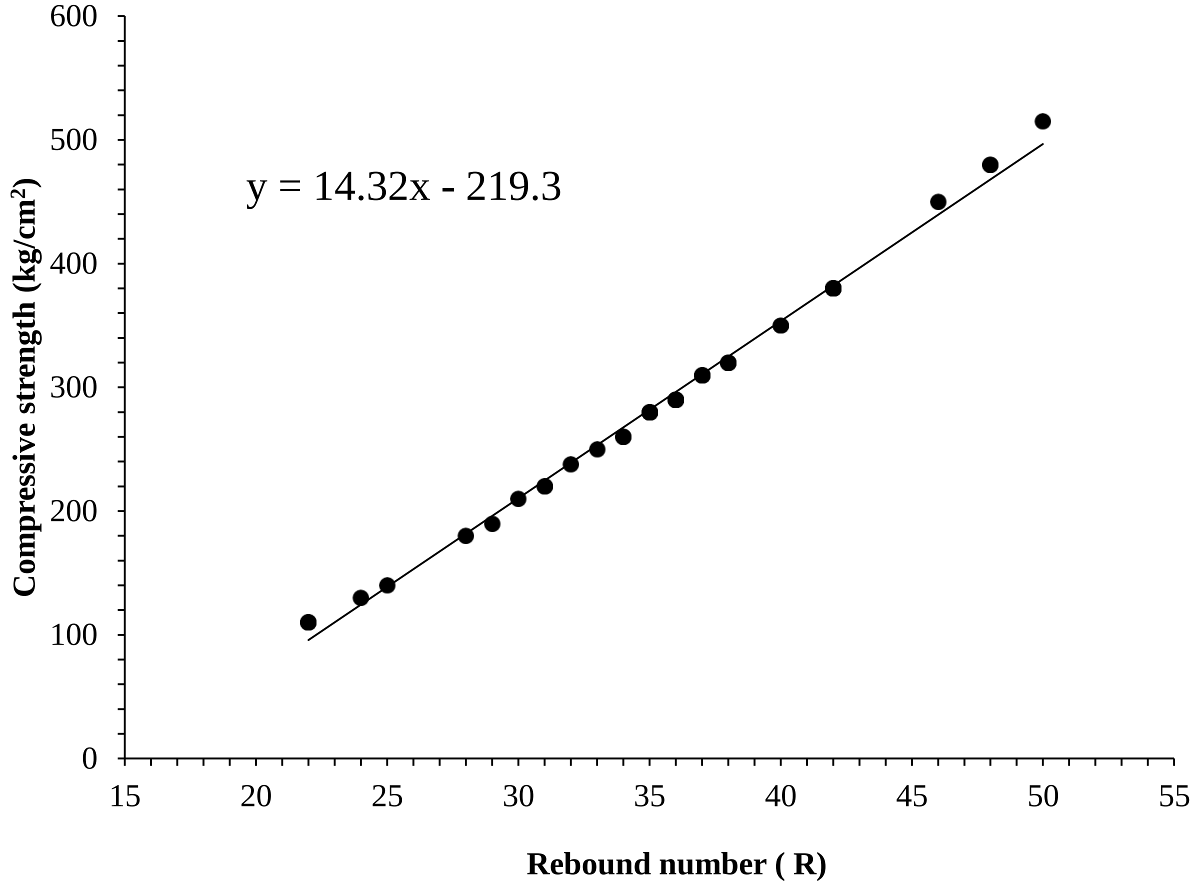

Fig 4.5: Relationship between N and UCS for seam3, Ananta OCP

Following are the Rebound Number values obtained using Schmidt Rebound Hammer for seam4, Ananta OCP and the UCS values were calculated using figure 2.1.

Table 4.8: Rebound number and UCS values for seam4, Ananta OCP

Serial number	Rebound number (N)	UCS(kg/cm^2)
1	36	290
2	42	380
3	26	158
4	29	190

5	40	350
6	38	320
7	35	280
8	43	400
9	51	530
10	48	480
11	29	190
12	26	158
13	37	310
14	35	280
15	36	290
16	36	290
17	41	370
18	38	320
19	48	480
20	50	515
21	37	310
22	37	310
23	42	380
24	54	580
25	32	238
26	28	180
27	37	310
28	41	370
29	40	350
30	35	280
31	32	238
32	42	380
33	51	530
34	50	515
35	37	310
36	38	320
37	26	158
38	28	180

Considering table 4.8 Compressive strength was plotted against Rebound number values which shows linear relationship among them.

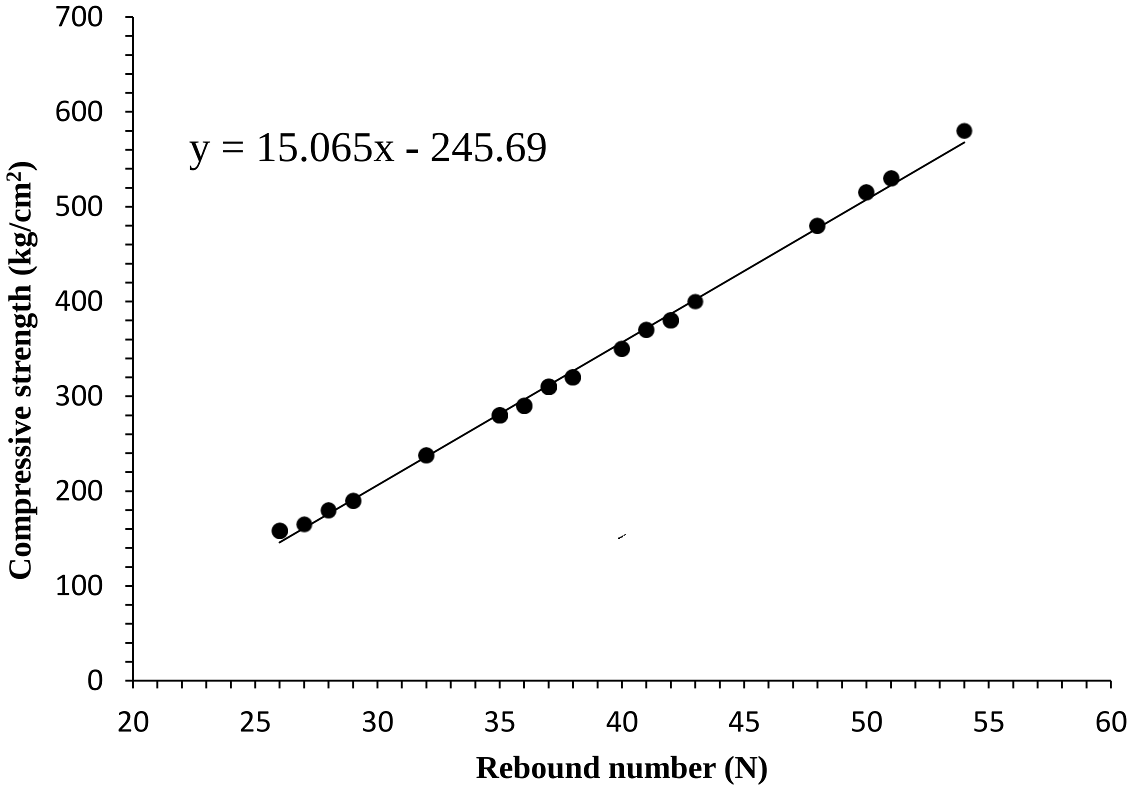

Figure 4.6: Relationship between N and UCS for seam4, Ananta OCP

After performing all the measurements both by in-situ and laboratory following table has been drawn.

Table 4.9: Predicted UCS values and Measured UCS values

Day	Name of the seam	No. of readings taken	Average rebound number	Predicted UCS (kg/cm^2)	Measured UCS (kg/cm^2)
1	Upper Lajkura seam, Lajkura	15	36.46	303.53	294
2	Lower Lajkura seam, Lajkura	15	38.4	332.4	312

3	Seam1, Ananta OCP	43	37.09	276.8	280
4	Seam2, Ananta OCP	36	34.03	270.72	290
5	Seam3, Ananta OCP	39	35.59	290.33	290
6	Seam4, Ananta OCP	38	37.82	324.12	305

Considering Table 4.9 following relationship was plotted between Rebound number values and Compressive strength and the regression coefficient has been found out to be 0.8514.

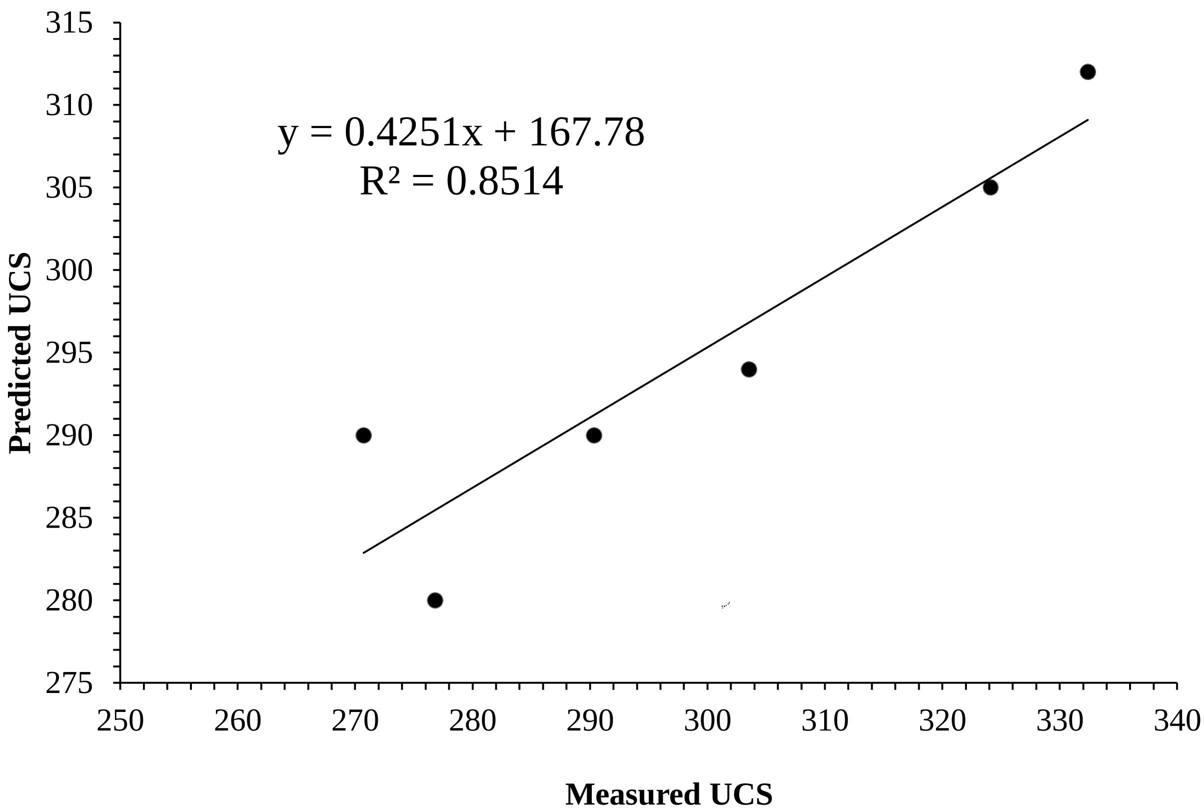

Figure 4.7: Relationship between Predicted UCS and Measured UCS

4.3 Summary

The governing equation of 6 different seams obtained from their rebound number and UCS values are as below:

Table 4.10: Equation for different seams

Seam	Equation
Upper Lajkura seam, Lajkura	y = 14.895x - 239.65
Lower Lajkura seam, Lajkura	y = 14.905x - 239.96
Seam1, Ananta OCP	y = 14.948x - 242.27
Seam2, Ananta OCP	y = 14.051x - 211.32
Seam3, Ananta OCP	y = 14.32x - 219.3
Seam4, Ananta OCP	y = 15.065x - 245.69

Then all the Rebound Number data were combined to find out the average UCS value for each seam as obtained by the Rebound Number were calculated. The predicted UCS values were compared with the measured UCS values in Table 4.9. It has been observed that there exists a close resemblance between the two. The mean value was found to be 295.16 and standard deviation is 11.53.

Chapter 6

Conclusion

Conclusion from the investigation are as follows:

1. 6 different faces from 2 different mines were considered for the test.
2. The face tested varied between a depth of 20-60m.
3. The average Rebound Number of coal varied between 34-38.
4. The average UCS of coal varied between 270-330kg/cm^2.
5. There exist a close relation between Rebound Number and UCS as obtained from regression analysis with regression coefficient varied between 0.85-0.93.
6. There exist a very close relation between predicted UCS and measured UCS.
7. Governing relation is $y = 0.4251x + 167.78$ with regression factor, $R^2 = 0.85$.

Scope for future Research

This exercise was carried out in a limited period of time. This can be carried out for large number of faces and for different types of rock using different geological condition to collect more data and hence a comprehensive conclusion.

Reference

1. S.R. Torabi, M. Ataei, M. Javanshir, *Application of Schmidt rebound number for estimating rock strength under specific geological conditions*, Faculty of Mining, Petroleum and Geophysics, Shahrood University of Technology; Shahrood, Iran Faculty of Mining Engineering, Birjand University; Birjand, Iran
2. Bieniawski, Z.T., (1968), *The effect of specimen size on compressive strength of coal*, Int. J.Rock Mech. Min. Sci., Vol. 5, pp. 325-335.
3. Bieniawski, Z.T., (1974), *Estimating the strength of rock materials*, Journal of the South African Inst. of Mining and Metallurgy, Vol. 74, pp. 312-320.
4. Bieniawski, Z.T. and Van Heerden, W.L. (1975), *The significance of in-situ tests on large rock specimens*, Int. J. Rock Mech. Min. Sci., Vol. 12, pp. 101-113.
5. Bishop, A.W., (1966), *The Strength of Soils as Engineering Materials*, Geotechnique, Vol. 16, pp. 91-130.
6. ACI 228.1 R-03, In-Place Methods to Estimate Concrete Strength, American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333-9094
7. U.S. Department of Transportation Federal Highway Administration, *Guide to Nondestructive Testing of Concrete*, September 1997, Publication No. FHWA-SA-97-105, 400 Seventh Street, SW, Washington, DC 20590
8. Adel Asadi (Islamic Azad University), *Uniaxial Compressive Strength using Schmidt Hammer Rebound Number Data under Specific Geological Conditions*, International Society for Rock Mechanics, Document IDISRM-EUROCK-2015-177
9. ISRM (1981). Rock characterization testing and monitoring ISRM suggested methods, suggested methods for determining hardness and abrasiveness of rocks, Part 3,101–3.
10. Bhanwar S. Choudhary, Kumar Sonu, *Assessment of powder factor in surface bench blasting using schmidt rebound number of rock mass*, Assistant Professor, B.Tech Student, Department of Mining Engineering, Indian School of Mines, Dhanbad-826004
11. ISRM C805-08, Standard Test Method for Rebound Number of Hardened Concrete, American Society for Testing and Materials, West Conshohocken, PA
12. Schematic view of a Schmidt Hammer, https://www.gardco.com/pages/hardness/schmidthammer.cfm
13. Working of Schmidt Hammer, http://www.engineersdaily.com/2011/04/rebound-hammertest.html
14. Universally accepted graph for quick measurement of UCS, http://www.ndtjames.com/Manual-Rebound-Hammer-p/w-m.htm