DEVELOPMENT OF A NEEDLE PENETROMETER DEVICE AND EVALUATION OF ITS PERFORMANCE

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DEVELOPMENT OF A NEEDLE PENETROMETER DEVICE AND EVALUATION OF ITS PERFORMANCE

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By

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Supervisor's Certificate

This is to certify that the work presented in the dissertation entitled *Development of a needle penetrometer and evaluation of its performance* submitted by *Pankajkumar Kanchan Ram*, Roll Number *214MN1370*, is a record of original research carried out by him under our supervision and guidance in partial fulfillment of the requirements of the degree of *Master of technology* in *Mining Engineering*. Neither this dissertation nor any part of it has been submitted earlier for any degree or diploma to any institute or university in India or abroad.

Dr. Manoj Kumar Mishra

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ABSTRACT

Mining and excavation activities involve dealing with earth materials typically rock mass of varying properties. The mechanical properties of rocks play major in successful excavation process. However the determination of correct strength values is a challenge as rock properties vary widely. Obtaining the right sizes for strength test are very difficult due to structural variation. Innumerable attempts have been made to predict rock properties. Needle penetrometer is one such unit developed to predict compressive strength of rock from the surface testing. It measures the surface behavior and correleate the same with the compressive strength parameter. In this investigation a needle penetrometer using mild steel material has been developed as per the ISRM (2014) suggested guidelines. Different parts were fabricated and one unit was prepared. Five different coal samples collected from varying depth from 480 m to 580m and their behavior were measured. Both th unconfined compressive strength and needle penetration index values of these sample were determined. Six established approaches Ulusay and Erguler (2012), Aydan (2012), Uchida et al. (2004), Okada et al. (1985) and Takahashi et al. (1988) and Yamaguchi et al. (1997) were compared with the measured results. It was observed that the measured values compared favourably with that of Okada et al. (1985).

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Introduction

1.1 INTRODUCTION

Estimation of mechanical properties of intact rock is generally required for determining the stability of rock strata. They are additionally important components in rock classification used in empirical assessment of rock masses. Estimation of these properties requires lab testing, which must be performed on tests of certain measurements to satisfy testing norms and/or proposed techniques. Laboratory tests are likewise tedious because of sample preparation, and in addition test systems regularly require high-capacity loading devices. Needle penetration tests (NPTs) are used for inferring the uniaxial compressive strength of soft rocks. Penetrometers are common devices for estimating UCS of weak rocks, and lots of studies have been published about them thus far.

1.2 MOTIVATION FOR THE PRESENT RESEARCH WORK

Sedimentary rocks make up the major parts (about 70 %) of rocks in geological formations. More than 60 % of these rocks are weak and contain clay minerals. Civil and mining projects are no exceptions, and one is likely to confront sedimentary rocks in lots of these projects. Due to the structural weaknesses of these rocks and sensitivity of their clay minerals to humidity, in these projects, weak rocks may cause a number of problems, especially in the presence of humidity. Therefore, if these rocks exist in either civil or mining projects, gathering acceptable range of data as to the structure of the rocks and their mechanical characteristics would be critical. Especially in prefeasibility and feasibility studies since studying, designing, and performing the project should be done regarding this fundamental information in order to reduce the potential problems, which might arise if the characteristics of these types of rocks are overlooked. However, there are serious difficulties in obtaining rock mechanical properties of some sedimentary rocks. It could also be a serious problem for measuring mechanical properties of these rocks because of the high-quality core specimens recommended by testing standards or suggested methods for uniaxial compressive strength (UCS), so determinations cannot always be obtained, particularly from weak, thinly bedded and clay-bearing rocks. In view of this difficulty, some modeling methods and also some simple index test methods such as point load, Schmidt hammer, and block punch index (BPI) tests have been developed in order to indirectly estimate the UCS. However, preparation of small specimens from such rocks for some of these simple index tests like BPI and point load could sometimes be difficult.

For resolving this issue, needle pentrometers were developed by many manufacturers. It is non-destructive index test to find the UCS. One of the most important advantages of these devices was their direct indication of compressive strength.

1.3 OBJECTIVES OF THE PROJECT

- To design needle penetrometer device based on reference to ISRM suggested method for the needle penetration test
- Fabrication of the device
- To test on coal samples and calculate NPI
- Comparison between measured UCS and predicted UCS through established approaches

1.4 LAYOUT OF THE THESIS

The thesis consists of steps, measures and analysis needed to develop a needle penetrometer and to evaluate its performance with respect to few samples.

Chapter-1 consist of the background of the problem, specific objective and methodology followed to achieve this object.

Chapter-2 reflect an exhaustive critical review of pertinent literature sourced from books, journals, articles, personal communication as well as other sources.

Chapter-3 deals with material selection, the design of individual parts and its specification.

Chapter-4 gives the detail idea about fabrication of the device and testing results for different sample

Chapter-5 shows releationship between NPI and measured UCS, results obtained from eastablished equations to predict UCS.

Chapter-6 concludes the findings of the study and proposes scope for future work.

At the end references has been given.

Chapter-2

Literature Review

2.1 INTRODUCTION

Rock engineers broadly utilize the uniaxial compressive strength (UCS) of rock in outlining surface and underground structures. The technique for measuring this rock strength has been institutionalized by both the American Society for Testing and Materials (ASTM) [1] and the International Society for Rock Mechanics (ISRM) [2]. In spite of the fact that, the strategy is generally straightforward, it is tedious and costly; likewise, it requires very much arranged rock samples. Along these lines, indirect tests are regularly used to find the UCS, for example, Schmidt hammer, point load index, impact strength and sound velocity. These test are easier to carry out because they require less sample preparation and testing instrument is sophisticated. Additionally, they can be utilized effortlessly as a part of the field. Thus, compared to uniaxial compressive test, indirect test are more straightforward, speedier and more practical. Some commonly used indirect test methods for finding UCS are as

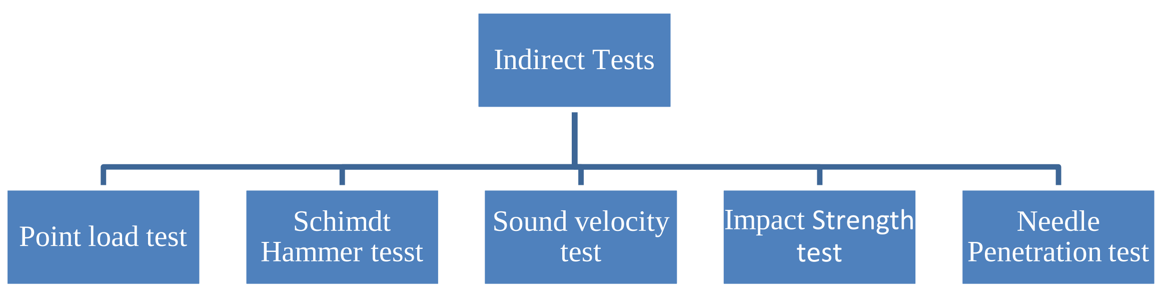


Figure 2.1: Different Indirect Tests for inferring rock properties

2.1.1 Point Load Test

In a Point Load Test, a sample of rock is mounted between two pointed platens and weight is connected until fracture of the specimen happens. The maximum load applied is recorded and used to figure the Point Load Index. It has been utilized generally as a part of practice because of its testing ease, effortlessness of example arrangement, and field applications. The compressive quality is roughly equivalent to 24 times the point load list (Is), referred to a standard size of 50 mm

Point load strength index (Is) = $(P \times 1000)/D^2$ Mpa

Where P is breaking load in kN.

D is the distance between platens in mm.

2.1.2 Schmidt Hammer Test

A Schmidt hammer, otherwise called a Swiss hammer or a rebound hammer, is a gadget to quantify the flexible properties or quality of cement or rock, basically surface hardness and penetration resistance. The Schmidt measures the rebound back of a spring-stacked mass affecting against the surface of the example. The test hammer will hit the solid at a certain impact. Its hardness depends on the rebound of the mass-spring system which is measured by the equipment.

Figure 2.2: Schmidt Concrete Test

When conducting test Schmidt hammer should be held at right angle to the surface. Surface should be polished and smooth otherwise it will give wrong reading as orientation of hammer affects the result. The rebound arbitrary scale is from 0-100

2.1.3 Sound Velocity Test

Seismic overviews have been done in site and research facility examinations. Attempts have been made to survey grouting, rockbolt reinforcement and blasting efficiencies in the rock mass by the seismic speed determination. Ultrasonic pulse is send to test the nature of concrete and common rocks. In this test, the quality and nature of cement or rock is surveyed by measuring the speed of an ultrasonic pulse going through a solid structure or characteristic rock arrangement. This test is led by passing a beat of ultrasonic wave through cement to be tried and measuring the time taken by pulse to traverse the structure. Higher speeds demonstrate great quality and congruity of the material, while slower speeds may show concrete with numerous splits or voids.

2.1.4 Impact Strength Test

Protodyakonov Impact Strength Index (PSI) is a way of characterizing coal strength, which has immense possibility for practical implementation in coal cutting and drilling. It also gives an idea about the uniaxial compressive strength of the rock. Impact strength index test is first discovered by Protodyakonov to put forward an idea about the Rock's strength properties, cuttability and brittleness, then is improved by Evans & Pomeroy (1966). 100 gm sample is taken for coal from sieve of -4.75 mm to +3.35 mm. 50 gm is taken for rock, sample is filled in cylinder. Plunger of mass 2.4 kg is dropped from height of 30.48 cm, 20 times for rock and 15 times for coal. The crushed sample is then sieved through 0.5 mm and remained product is measured in volumeter for height 'h'.

The protodyakanov strength index is calculated by

$$P.S.I = (20\times n)/h$$

Where 'n' is number of blows

And 'h' is height of volumeter

2.1.5 Needle Penetration Test

The needle penetration test is a non-destructive indirect test relevant both in the field and lab to decide the needle penetration index (NPI) and does not require any high-quality sample preparation. A few creators have built up a few relationships between NPI values and other physico-mechanical properties of intact rock for various rock types. The NPI value is mainly used to infer the UCS of intact. NPI index is ratio of load applied to the depth of penetration of needle.

2.2 SCOPE

The needle penetration test can be performed in the field on rock exposures or in lab on rock samples. It utilizes a light convenient device, called needle penetrometer that pushes a needle into the rock.

The needle penetration test is used for the determination of the needle penetration index (NPI). This index value can be utilized to estimate other physico-mechanical properties of intact rock with which NPI is related, such as UCS.

2.3 TESTING DEVICE

The needle penetrometer (NP), a lightweight portable device (about 600–700 g), is used to make a needle penetrate into a rock surface. The needle is a hardened steel, 0.84-mm-diameter rod terminated by a conical tip. It is a sewing needle designated as JIS S 3008.

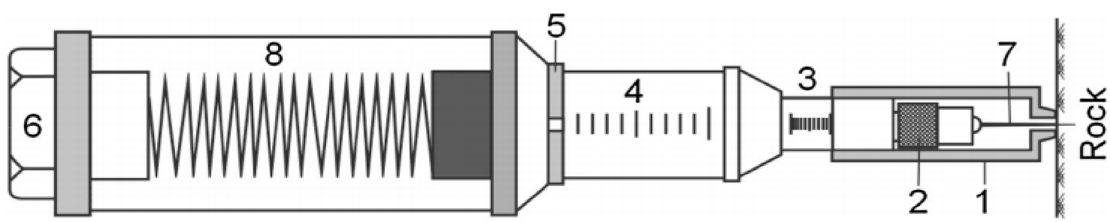


Figure 2.3: Needle Penetrometer and its parts: 1. Presser, 2. Chuck, 3. Penetration scale, 4. Load scale, 5. Load indicating ring, 6. Cap, 7. Penetration needle and 8. Spring [5].

The device principally comprises of presser, chuck, penetration scale (0–10 mm, 1 mm graduation), load scale (0–100 N, 10 N graduation), load marker ring, top (removable; penetration needles contained in the grasp), penetration needle and spring mounted in the penetrometer hold as appeared in Fig. 2.3. To embed the needle, the presser (Fig. 2.3, section 1) is expelled from the penetration scale (Fig. 2.3, section 3) utilizing the vertical and even indents, the chuck (Fig. 2.3, section 2) is turned counterclockwise and the entrance needle is embedded. At that point the chuck is turned clockwise to fasten and settling the needle and the presser is set utilizing the co-pivotal indent for zero point modification of the penetration scale. The load indicator ring is manually adjusted to zero.

The device can measure upto maximumum 100 N and the needle penetration depth is till 10 mm [6]. In spite of the fact that this test has been utilized for rocks with UCS up to 35 MPa, it is for the most part suggested that it ought to be utilized for rocks with UCS lower than 20 MPa, to acquire reasonable results the penetration of the needle ought to be more than 1 mm without bringing about any harm to the needle.

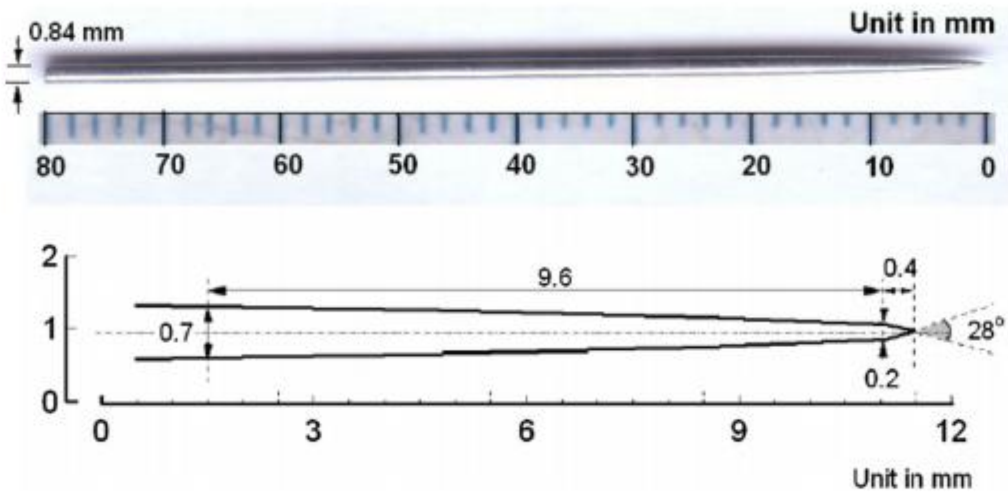


Figure 2.4: Standard needle for NP and its geometry [4]

2.4 RANGE OF DIFFERENT INDEX TESTS

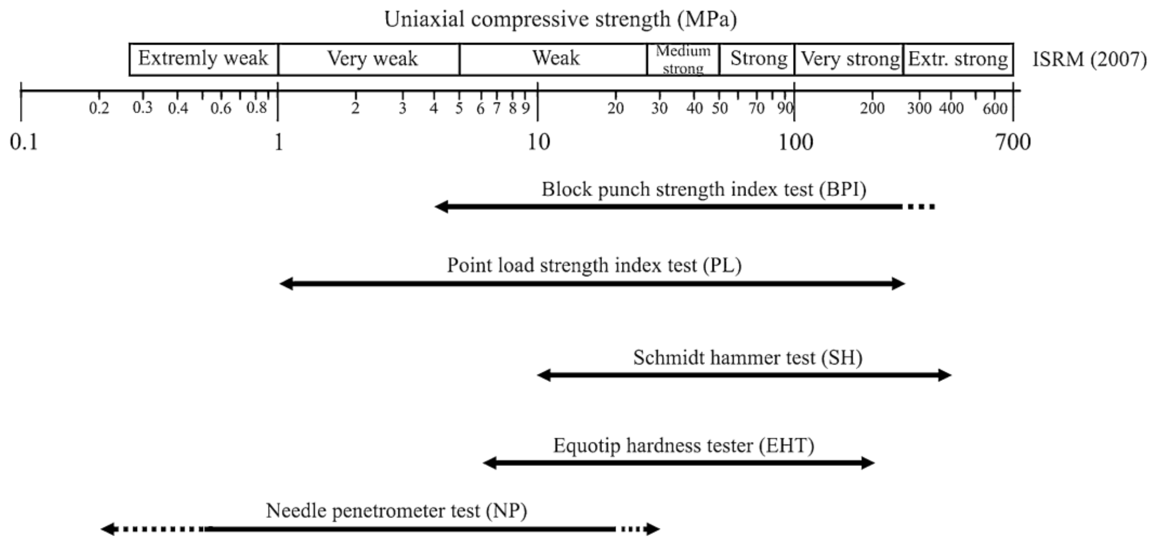


Figure 2.5: Some common index test in rock engineering and their ranges of applicability for estimating the UCS [3].

2.5 PROCEDURE TO PERFORM TEST ACCORDING TO ISRM

The needle penetrometer (NP) device can be utilized both on rock exposures as a part of the field and on samples with cylindrical, cubic or prismatic shapes made from cores or blocks. It doesn't require any special preparation for sample. However before testing if there are asperities it need to be removed. Since the test is done on soft/weak rocks, removal of these asperities by simple grinding can be done with help of common instruments such as sandpaper, file or pocketknives.

The extent of tests ought to be such that no part of some specimens happens. In light of the experience, splitting may happen in lab tests having a size of 35×35×35 mm. Consequently, test size is proposed to be around 40×40×40 mm for prismatic samples and 40–50 mm for cylindrical sample which have height greater than 15mm. NP test is applicable in all direction [5].

The test is performed by holding truncated tapered joint amongst burden and relocation graduations with one hand and the principle body with the other hand firmly, and gradually the penetrometer needle into the stone surface or example physically. The heap ought to be connected oppositely to the surface. It is prescribed that clients hold the needle penetrometer dependably similarly situated, i.e., with both hands. It ought to be noticed that if the administrator turns out to be less engaged and begins evolving his/her standard usual way of doing things (e.g., holding the penetrometer with only one hand), the dispersing of the NPI qualities will increment.

The needle is pushed into the stone until 100 N is come to; at this stage the depth of penetration is measured from the position of the presser on the penetration scale then, the needle is gradually taken out. With milder and immersed rocks, it is conceivable that before the max. penetration force is achieved, the max. penetration depth (10 mm) is accomplished. For this situation, the test stops at this depth, the load applied for pentration is read from load scale

The test is over and again done on the same surface between three to five times. Be that as it may, if the outcomes are not reliable or excessively scattered, the quantity of tests can be expanded. At every time, the penetration needle of the needle is moved by no less than 10 mm from the past point.

During penetration, some breaks may create and may make a radially cracked zone. It ought to be noticed that when the needle is pulled back, some rearranged cones and related cracks may likewise create. In the event that cracks is created during the penetration procedure, the consequences of such tests ought to be disposed of. Nonetheless, if such cracks create during the withdrawal of the needle, the test can be acknowledged as legitimate. If during penetration test splitting of sample takes place due to tension along a weakness plane, such as bedding then such test should be discarded.

2.6 CALCULATION OF NPI INDEX

NPI index is ratio of load applied to penetrate the needle to the depth of penetration. The values of NPI should be between 100 N/mm and 1 N/mm as minimum graduation of the penetration scale is 1 mm and that of load scale is 100 N.

It is calculated by equations

For F=100 N and D≤10 mm,

$$\text{NPI}=\frac{100}{D}$$

For D=10 mm and F<100 N

$$NPI=\frac{F}{10}$$

Where F is the applied load and D is the depth of penetration. NPI is ratio of these two parameters so, unit of NPI is N/mm

The mean of the NPI values ascertained utilizing no less than three purposes of estimation on the same testing surface is taken as the NPI estimation of the example or rock presentation. In spite of the fact that the impact of the needle penetration rate on the NPI is immaterial, every test ought to take around 30 s to perform.

In certain sorts of rocks showing grain or porosity heterogeneity at the size of the needle breadth (e.g., grains bigger than 10 mm, uneven dissemination of pores or a blend of crushable with less crushable grains), an extensive dissipate of the NPI qualities is normal. On account of rocks with coarse hard grains in a delicate solidifying material, for example, breccia or aggregate, the NP test can be circumspectly used to surmise the properties of the soft matrix.

2.7 ADVANTAGES OF NPI INDEX

- Deduction of other index properties such as UCS, tensile strength, young's modulus, cohesion and friction angle.
- It can be easily calculated

2.8 RELATION BETWEEN NPI AND OTHER INDEX PROPERTIES

The NPI value is mainly used to estimate the UCS of intact rock. The connections between's the NPI are investigated and a few experimental relations are introduced to derive different geo-mechanical properties, for example, water content, elastic modulus, UCS, Brazilian tensile strength, elastic wave speed, friction angle, and cohesion. At that point, a few uses of the NPT to portray the geo-mechanical properties of flaw/break and slip (shear) surfaces are given.

Table 2.1: Empirical prediction equations to calculate some mechanical properties of rocks using NPI [5].

Rock Material Property	Equation	Recommended by	Rock types tested
Uniaxial compressive strength, σ_c	σ_c(MPa) = $0.4NPI^{0.929}$ (N/mm)	Ulusay and Erguler (2012)	Marl, tuff, mudstone, siltstone, greywake, very stiff clay; data from Japan
	σ_c(MPa) = $0.2NPI$ (N/mm)	Aydan (2012)	Tuff, sandstone, pumice, limestone, lignite measures
	σ_c (kPa) =27.3NPI+132 (N/cm)	Uchida et. Al (2004)	Sandstone
Tensile strength, σ_t	$\sigma_t = 0.02\ NPI$ (NPI, N/mm)	Aydan (2012)	Tuff, sandstone, pumice, limestone, lignite measures
Young's modulus, E_i (GPa)	$E_i = 0.05\ NPI$ (NPI, N/mm)	Aydan (2012)	Tuff, sandstone, pumice, limestone, lignite measures
P-wave velocity, V_p (km/s)	$V_p = 0.33 + 0.3NPI^{0.5}$(NPI,N/mm)	Aydan (2012)	Tuff, sandstone, pumice, limestone, lignite measures
Cohesion, c (MPa)	c = 0.04 NPI (NPI, N/mm)	Aydan (2012)	Tuff, sandstone, pumice, limestone, lignite measures
Friction angle ϕ (°)	ϕ = 54.9(1-exp(-NPI/10) (for tensile regime) ϕ = $13.375NPI^{0.25}$ (for compressive regime)	Aydan et al. (2013)	Tuff, sandstone, pumice, limestone, lignite measures

S-wave velocity, V_s(km/s)	$V_s = 0.1 + 0.18NPI^{0.5}$ (NPI,N/mm)	Aydan et al. (2013)	Tuff, sandstone, pumice, limestone, lignite measures

2.9 OVERVIEW OF RESEARCH WORK RELATED TO NPT

JSCE-RMC (1980) Needle penetrometer was developed in Japan and released as a suggested method by the Rock Mechanics Committee of the Japan Society of Civil Engineers[1].

JSCE (Japan Society of Civil Engineers) (1991) revised the suggested method and published the JGS standard for needle penetration test that it is applicable for soft rocks having UCS less than 9.8 MPa [2].

Maruto Co. Ltd (2006) Needle penetrometer was developed by Maruto Company based on the suggested guidelines by JSCE [15].

Aydan et al. (2012) Relationship for inferring physio-mechanical properties of soft rock. NPI was used for estimating other properties of rock such as s-wave velocity [6].

ISRM suggested method for the needle penetration test. *Rock mechanics and rock engineering* 47, no. 3 (2014): 1073. Needle penetration test by needle penetrometer was suggested as standard. Procedure to perform the test, reporting of result and range of applicability was suggested [5].

Azadan Pedram et al. (2014) performance evaluation for new dynamic needle penetrometer developed by Eijkelkamp Netherland was done. Comparision between NP and suggestion for dynamic NP was given. Eijkelkamp NP was found to be more accurate.

Chapter-3

Materials and specification

3.1 INTRODUCTION

Engineering design is the creation of plans for machines, structures, systems, or process to perform desired functions. For designing a machine component, there is no rigid rule. The general procedure adapted was the basic machine design process to develop the device. Individual parts were to be developed followed by material selection and fabrication to perform the desired output.

3.2 STEPS FOLLOWED FOR DESIGN

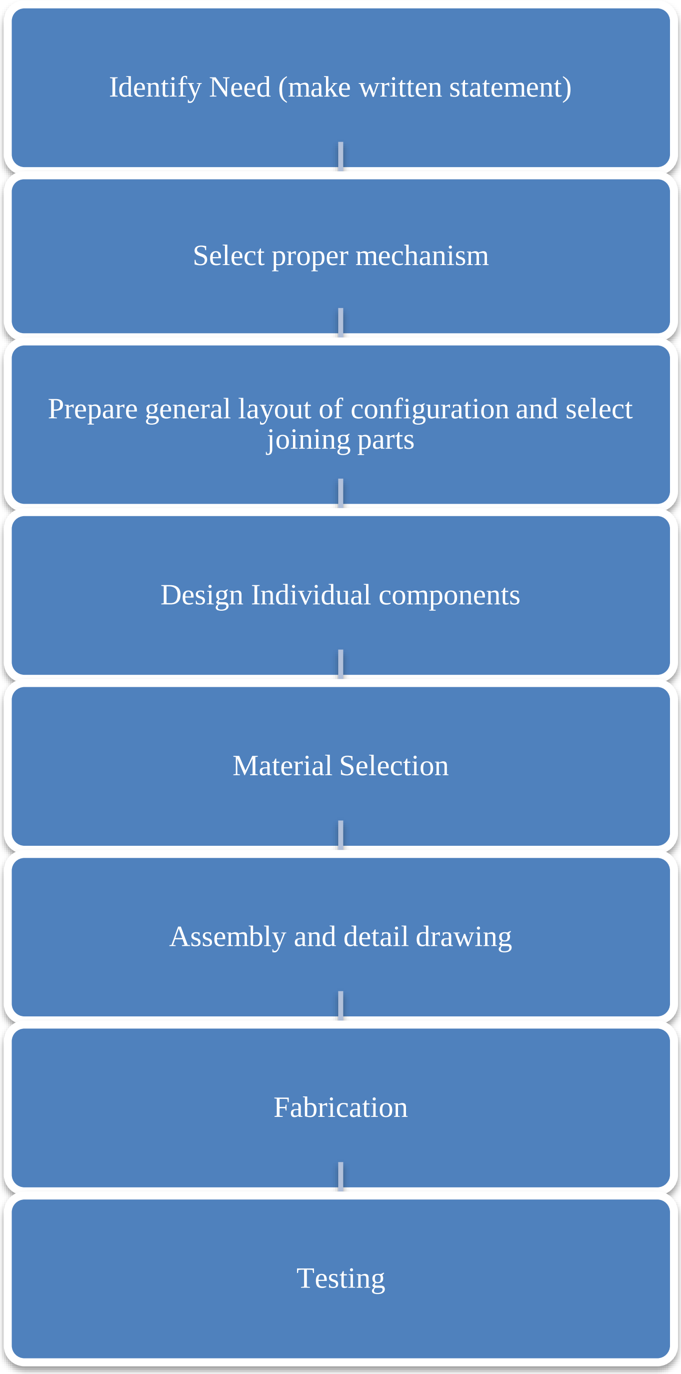
The design process include:

- **Recognition of need**. The need was to develop a device which has a calibrated load scale of 100N and which can penetrate needle into rock along with measurement of penetration.
- **Mechanism**. Stiffness of spring is used to calibrate load scale, deflection of spring against load application with chuck in front thus was basic mechanism
- **Analysis of Forces**. Compression spring is designed and analyzed for 100N load. With its length fixed to make compact and rigid design.
- **Material selection**. Individual material is selected based on application to make device cheap, low cost and lightweight.
- **Design of elements (size)**. Each element size was fixed with positive tolerance so that modification needed was done
- **Modification**. While Fabrication suggested size was bit modified to get the exact desired accurate design and better function.
- **Detailed drawing**. Assembly drawing as well as individual parts drawing was made in AutoCAD and is included below
- **Production**. Basic Lathe operations such as turning, drilling, facing was used to manufacture the parts.

3.3 FLOWCHART FOR DESIGN

Mechanical designing is a step by step procedure through which optimal design can be reached. Various factors are taken care of while following these steps such as cost, fabrication ease to get a better product which can be easily assembled and parts can also be replaced or serviced, if not working instead of making a complete product failure.

Figure 3.1: Flowchart for mechanical design



3.4 MATERIAL SELECTION

Material choice is a procedure which is performed to choose the best materials which may can possibly perform well both in modernly and monetarily. Today choice of materials is a critical piece of mechanical plans in light of the fact that the opposition in the business sector is substantial. Material selected should be cheap, readily available and should be durable. For making instrument a need was there that material should be economical so that overall cost of device is within range. It has to be easily machinable, weldability based on all these M.S (Mild steel) was selected.

Major Advantages of Mild Steel:

- Cost effective
- Can be easily machined
- Weldable
- Ductile
- Can be carburized i.e surface hardened

3.5 INDIVIDUAL PARTS AND SPECIFICATION

Table 3.1: Specification of parts

PARTS	DIMENSION(IN MM)	MATERIAL
Body	Diameter-60 Length-100	Mild steel (solid shaft) Grade
Cap	Diameter-70 Length-50	Mild steel (solid shaft)
Chuck	Diameter-16 Mini drill chuck	To hold 0.5-1.5 mm needles

Spring	Diameter outer-28 Diameter mean-25.5 Wire diameter-2.5 K=5 N/mm	Steel wire cold drawn Musical wire Capable to show load range 0-150 N on a scale of 0-30 mm Compression spring
Presser	Diameter-25 Length-70	M.S rod
Needle	Sewing Needle JIS S 3008	Hardened steel
Plunger	Diameter-25 Length-150	
Hexagonal Bolt	M20x20	

3.6 DESIGN

3.6.1 Compression Spring

There is frequent and varying loading as it is used for testing so selecting Music wire cold drawn carbon steel (0.7 to 1% carbon)

For compression spring design

Table 3.2: Spring design table

Material	A	M
Music wire	2190	00163
Oil tempered	1900	0.193
Hard drawn wire	1775	0.201

Design Formulae

Load range was from 0-100 N so design was done using 100 N as maximum load with a constraint of 30 mm diameter as the hole was fixed in body.

Factor of safety $\tau = \frac{8 \times D_m \times F \times k}{\pi d^3}$

τ- Working stress

i- active number of coils

D_0 – Outer diameter of spring

D_m – Mean diameter of spring

F- Applied load

k- spring stiffness

d- Wire diameter

Deflection $y = \frac{8 \times F \times D_m \times i}{G \times d^4}$

G- Modulus of rigidity

σ_u- Tensile strength

A, d^m- constants

τ_y – shear stress

Wire diameter $d = \sqrt[3]{\frac{8F \times D_m \times k_s}{\pi\tau}}$

$\sigma_u = (\frac{A}{d^m})$ MPa $\quad \tau_y = 0.435\sigma_u$

$\sigma_u = 1900/2^{0.193}$ = 1662 MPa

$\tau_y = 0.435 \times 1662$ = 578.4 MPa

$\tau = \frac{723}{1.25}$ = 578.4 MPa

D_0= 28mm $\quad D_m$= 26mm

k_s –Stress factor

C- spring index

C=$\frac{26}{2}$ = 13 $\quad k_s$ = 1+1/2C = 1.038

$$d = \sqrt[3]{\frac{8 \times 120 \times 26 \times 1.038}{\pi \times 578.4}}$$

= 2.6 mm

Taking it as standard available size d =2.5 mm

$$i = \frac{Gd}{8c^3k} = 4.58\ coils = 5$$

$L_0 -$ Total length

$$L_0 = \text{Solid length} + y_{max} + \text{clash allowance}$$

$$= (i + 2)d + 30 + 3$$

$$= 7\times 25 + 33$$

$$= 50.5 \text{ mm}$$

Final Specification of spring,

D_0 = 28 mm D_m = 25.5   k = 5 N/mm

d = 2.5 mm   i = 5

Length = 50 mm

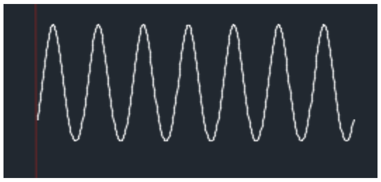


Figure 3.2: CAD model of spring

Spring restores the compression force experienced by plunger and length of Compression is measured due to scale on plunger which gives the load applied, when multiplied by stiffness (5N/mm).

3.6.2 Body

Body is a hollow shaft, act as a guiding frame to the plunger and has spring within it. During application of force this body is hand-held and pressure is applied to give the penetration reading. It constraint the motion of plunger to linear thus making able to penetrate in sample.

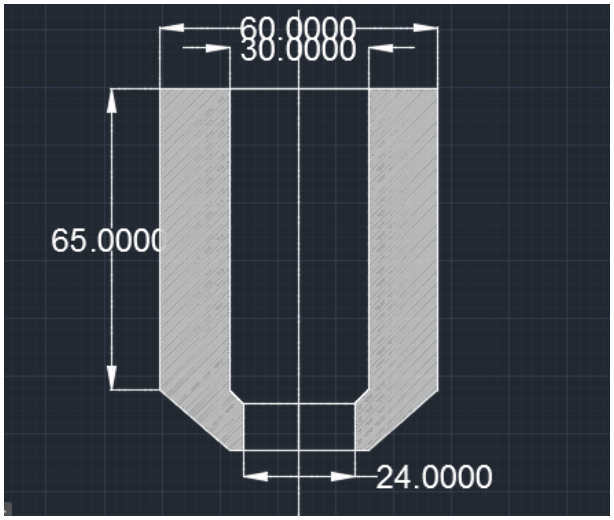


Figure 3.3: CAD drawing of body

3.6.3 Cap

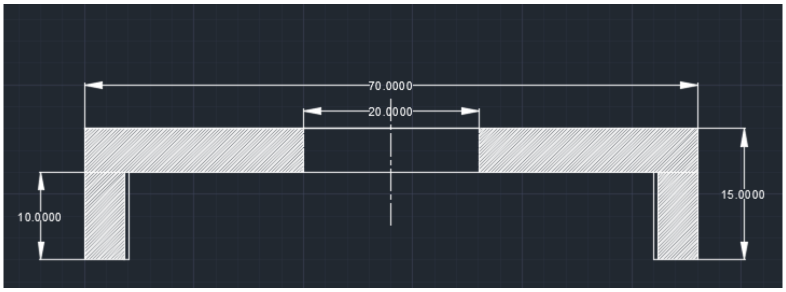


Figure 3.4: CAD drawing of cap

Cap locks the assembly of spring, plunger and body together with threading. For opening the assembly it is rotated anticlockwise and nut is loosened.

3.6.4 Plunger

Plunger slides within the body when force is applied. Retraction of plunger is due to spring as it stores during compression. At the front end chuck with needle is assembled.

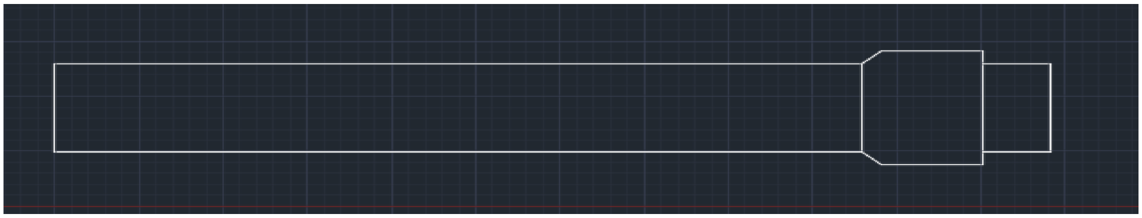


Figure 3.5: CAD drawing of plunger

3.6.5 Chuck

A chuck is a specialized type of clamp. It is used to hold an object with radial symmetry, especially a cylinder. In drills and mills it holds the rotating tool whereas in lathes it holds the rotating workpiece. Mini Drill chuck holds the needle, locking is by inserting needle and rotating the chuck anticlockwise. To change needle reverse action need to be done. Presser cover the chuck, its surface coincides with needle tip. It holds needle along the axis to provide perpendicular contact with surface which in turn push the presser up on penetration scale showing the needle depth penetrated reading.

Figure 3.6: Image of Chuck

Specification:

- Capacity: 0-.040" (1mm)
- Shank: 1/8"
- Black Oxide Finish
- Overall Length: 1.3"

3.6.5 Presser

It is a hollow pipe with slot on it to make its motion constraint to linear. When pressed against sample it is guided by slot and travels along scale to show the depth of penetration. Its dimension is made to be in transition fit with plunger so that clearance is minimum.

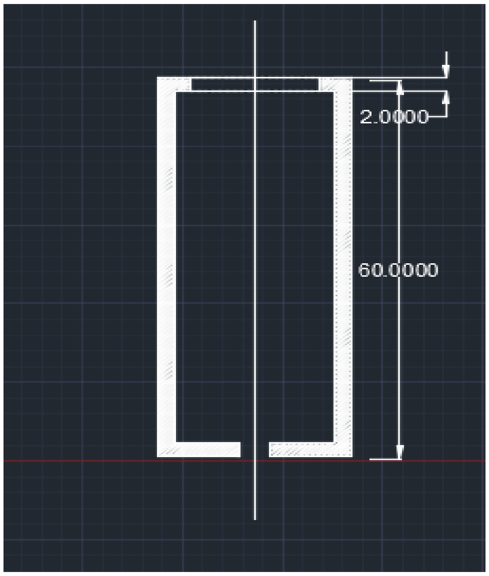


Figure 3.7: CAD drawing of presser

Chapter-4

Fabrication and testing

4.1 INTRODUCTION

Fabrication is building of product by cutting, bending, and assembling processes. It is a value added process that involves the construction of machines and structures from various raw materials. For the project, raw materials (M.S rod) were shaped to get desired part using lathe operations. Machine used in fabrication was Central Lathe, CNC lathe and Centre drill and for joining operation gas welding was used. It was needed that each part should be fabricated with accuracy for exact reading.

4.2 LATHE

It is a machine which rotate the workpiece along its axis to perform various operations such as turning, facing, parting, drilling, or deformation with using tools for workpiece having symmetry about axis.

The working of the lathe machine changes with every operation and cut desired. Various operations are used in lathe machine some of the most common operations are as follows:

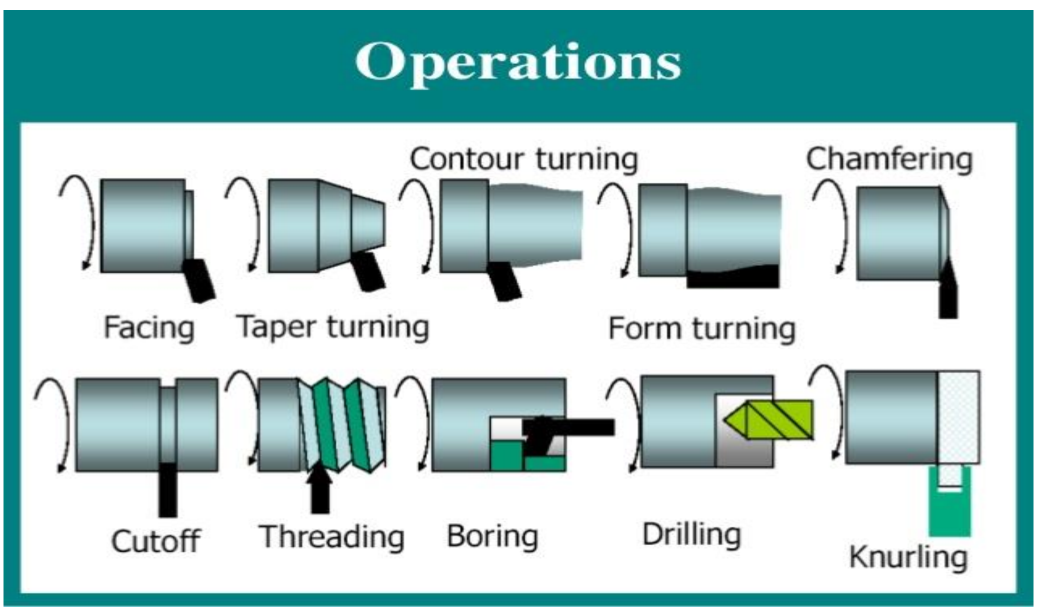


Figure 4.1: Various Lathe operations [16].

4.2.1 Facing

Facing is generally the first operation in lathe machine. In this process workpiece is faced (cut) to make it right angle along the axis for uniform machining.

4.2.2 Tapering

Tapering is cutting a material almost cone shaped and giving it slant. Diameter is reduced along the axis, one can increase the depth of cut for more taper.

4.2.3 Parallel Turning

Parallel turning operation is done to reduce the diameter of material along the axis uniformly. This operation is needed for removal of material and to achieve required dimension

4.2.4 Parting

The part is evacuated so it confronts the finishes. For this the parting tool is included in gradually to make perform the operation. For to make the cut more deep the parting tool is taken out and moved to the side for the cut and to prevent the tool from failure.

4.3 CNC LATHE

Computer numerical controlled (CNC) machines are quickly supplanting the more seasoned creation machines (multi-spindle, and so forth.) because of their simplicity of setting, operation, repeatability and exactness. They are intended to utilize present day carbide tooling and completely utilize current procedures. The part might be planned and the apparatus ways customized by the CAD/CAM process or physically by the software engineer, and the subsequent document transferred to the machine, and once set and trialed the machine will keep on turning out parts under the incidental supervision of an administrator.

The machine is controlled electronically through a PC menu style interface, the system might be changed and showed at the machine, alongside a reproduced perspective of the procedure. The setter/administrator needs an abnormal state of ability to perform the procedure, however the learning base is more extensive contrasted with the more seasoned creation machines where personal information of every machine was viewed as vital. These machines are regularly set and worked by the same individual, where the administrator will administer a little number of machines (cell).

Figure 4.2: CNC lathe

The configuration of a CNC machine fluctuates with various producers, yet they all have some basic components. The turret holds the apparatus holders and lists them as required, the shaft holds the workpiece and there are slides that give the turret a chance to move in numerous hub at the same time. The machines are frequently completely encased, due in huge part to word related wellbeing and security (OH&S) issues.

4.4 GAS WELDING

Gas welding is a welding procedure that melts and joins metals by heating them with a fire created by a response of fuel gas and oxygen. The most usually utilized strategy is oxyacetylene welding, because of its high flame temperature. The flux might be utilized to deoxidize and scrub the weld metal. The flux dissolves, sets and structures a slag skin on the resultant weld metal.

Advantages of Oxyacetylene welding

- Utilizes oxygen and a fuel gas to heat metal until it is in a liquid state and wire various bits of metal together. Can be utilized with or without a filler bar.
- Great for brazing divergent metals together.
- Older technology can be replaced by gas welding

Acetylene (C2H2) and oxygen is mixed to create a high temperature flame. Combination of metal is accomplished by passing the inward center of the fire over the metal Oxyacetylene can likewise be utilized for cutting metals

4.5 FABRICATION OF INDIVIDUAL PARTS

4.5.1 BODY

A 65 mm rod is turned to reduce its diameter to 60 mm using turning operation in lathe. Then a through hole of 20 mm was drilled so that plunger to fit inside. The end part was taper turned for better design and on top portion external threading was done to attach cap, cover the assembly.

Figure 4.3: Image of machined part (Body)

4.5.2 CAP

A 65 mm rod was bored to 55 mm, and internal threading was made. The cap is rotated over body for assembly. It is drilled with 20 mm hole for hexagonal bolt. The hole is internally threaded for bolt, this is done to completely cover the assembly.

Figure 4.4: Fabricated part (Cap)

4.5.3 PLUNGER

A rod of 25 mm was turned to diameter to reduce it to 20 mm till 108 mm of its length. A chamfer of 3 mm was given so that it sets smoothly in body during assembly. At the end portion leaving 20 mm from bottom side a hole for M8 bolt was done, for holding presser and plunger together during assembly. The hole was drilled using central drill machine

Figure 4.5: Central drill machine

The plunger was marked with load scale to measure load applied and also having scale for pentration of needle. The scale was marked on fabricated part.

Figure 4.6: Image of fabricated part (Plunger)

4.5.4 Attaching Chuck

Chuck was attached to plunger using gas welding. It need to be joined so that needle can be hold, and it should be straight.

Figure 4.7: Image of Gas welding attaching chuck

4.5.5 Presser

It was fabricated from G.I. pipe. It is hollow with internal diameter same as plunger diameter of 20 mm with little clearance. To make presser slide over plunger the need was there to make slot. Slot of 60 mm length was done on presser using automated CNC, with width of 8 mm so that M8 bolt can be used. The bolt was used with major purpose of holding the parts and guiding the presser over plunger scale.

Figure 4.8: Fabrication of Presser on CNC

4.6 ASSEMBLY

It was taken in consideration while designing that device should be easy to assemble with small parts to make it portable. The step to assemble were as follows:

- Step1: Body has to be firstly taken and plunger is assembled with chuck side (bottom side) by inserting it in body hole provided.
- Step2: After body and plunger assembly, the spring is kept inside body resting on plunger head provided for it.
- Step3: Cap is put to cover the upper assembly

- Step5: Load indicator ring is inserted on plunger after it is passed through the body from chuck side.
- Step6: Needle is holded in chuck by rotating it clockwise and then tighten anticlockwise to hold it straight.
- Step6: Presser is then taken to cover the chuck and slot is matched with drill hole. In the slot, bolt is put and tighten in hole with thread provided on plunger.
- Step7: Bolt is tighten in cap with thread provided.

Figure 4.9: Assembly of Needle penetrometer

4.7 TESTING

Testing was done on five different coal sample collected from different depth varying from 280 m to 580 m. Coal sample was selected for study because of availability of sample and as its UCS is of major concerned in coal mines. For each sample test was carried out for 10 times and average was taken as suggested by ISRM testing procedure.

Figure 4.10: Testing of samples

The average value of NPI was taken as final NPI. After each test the second one was carried out with a gap of 1 cm than previous needle mark. The result obtained from testing all five sample is shown in table below:

Table 4.1: Test result for coal sample

Sample ID	NPI
LHD-4	8.5
XVI B	14.28
XVII	11.11
XVI T	12.5
XV	15.38

Part of coal sample was used in laboratory to measure the UCS through direct laboratory tests. The UCS was determined based on standard test method, it was needed for analysis

Table 4.2: Direct Test result for coal sample

Sample ID	Measured UCS (MPa)
LHD-4	2.83
XVI B	4.15
XVII	3.8
XVI T	4.2
XV	4.67

Chapter-5

Results and discussions

5.1 INTRODUCTION

The usefulness of any device designed can only be verified after it is used and expected result is achieved. After development of needle penetrometer it was tested on five different coal sample. NPI was calculated for all sample and relation between NPI and measured UCS was found. The relation between NPI and measured UCS gives predicted UCS for sample by substituting NPI.

5.2 RELATIONSHIP BETWEEN NPI AND MEASURED UCS

For all sample points were scattered between NPI and measured UCS, this relation shows how both are related in this set of sample

Table 5.1: NPI and measured UCS for samples

Sample ID	NPI (N/mm)	MEASURED UCS (MPa)
LHD-4	8.5	2.83
XVIB	14.28	4.15
XVII	11.11	3.8
XVI T	12.5	4.2
XV	15.38	4.67

While regression the equation having highest value of R was taken and it was observed that for logarithmic it came maximum (best fit). The value of R^2= 0.9368 for logarithmic fitting.

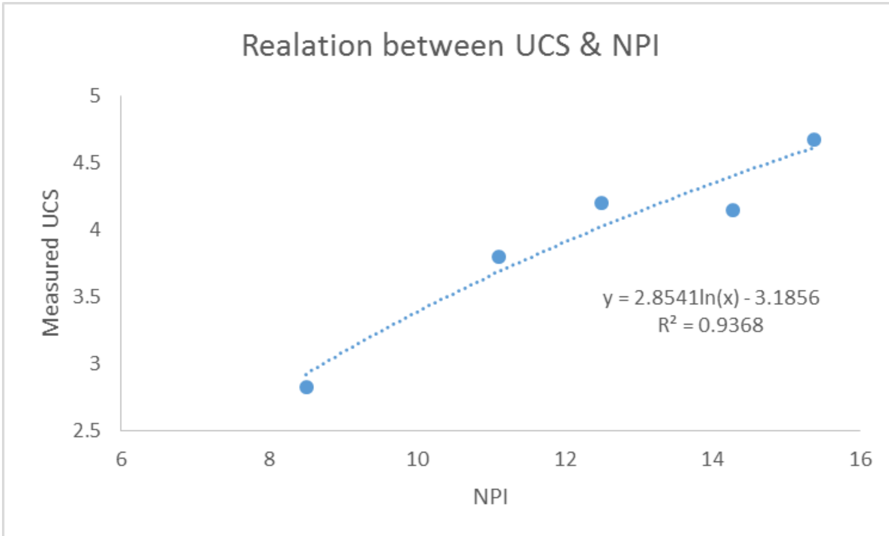


Figure 5.1: Relation between NPI and measured UCS

Equation governing the above relationship is

$$UCS = 2.854 \ln NPI - 3.1856 \text{.......................... (5.1)}$$

5.3 CALCULATION OF NPI FROM EXISTING EQUATIONS

Six established approaches Ulusay and Erguler (2012), Aydan (2012), Uchida et al. (2004), Okada et al. (1985), Takahashi et al. (1988) and Yamaguchi et al. (1997) were considered. Using value of measured UCS in these equations value of NPI is found. Since six different equation there was six NPI value for each sample

The equations are as follows:

$$\sigma_c(\text{MPa}) = 0.4NPI^{0.929} \text{ (N/mm)........................ (5.2)}$$

$$\sigma_c(\text{MPa}) = 0.2NPI \text{ (N/mm)............................. (5.3)}$$

$$\sigma_c \text{ (kPa)} = 27.3NPI + 132 \ (N/cm) \text{ .... (5.4)}$$

$$\log \sigma_c \ (kgf/cm^2) = 0.978 \log NPI + 1.599 \ (kgf/mm) \text{.......... (5.5)}$$

$$\sigma_c(\text{MPa}) = 1.539NPI^{0.9896} \text{ (N/mm)..................... (5.6)}$$

$$\log \sigma_c \ (kgf/cm^2) = 0.982 \log NPI - 0.209 \ (kgf/mm) \text{............... (5.7)}$$

For each equation σ_c was taken as measured UCS from table 3.2 for respective sample and NPI was calculated.

For sample 1 (LHD-4)

Table 5.2: NPI value for sample 1 from each equation

σ_c=2.83	Eqn. (5.2)	Eqn. (5.3)	Eqn. (5.4)	Eqn. (5.5)	Eqn. (5.6)	Eqn. (5.7)
NPI Through	8.21	14.15	9.89	7.07	1.85	49

For sample 2 (XVI B)

Table 5.3: NPI value for sample 2 from each equations

σ_c=4.15	Eqn. (5.2)	Eqn. (5.3)	Eqn. (5.4)	Eqn. (5.5)	Eqn. (5.6)	Eqn. (5.7)
NPI Through	12.41	20.75	14.72	10.46	2.72	72.5

For sample 3 (XVII)

Table 5.4: NPI value for sample 3 from each equation

σ_c=3.8	Eqn. (5.2)	Eqn. (5.3)	Eqn. (5.4)	Eqn. (5.5)	Eqn. (5.6)	Eqn. (5.7)
NPI Through	11.28	19	13.4	9.55	2.49	66.30

For sample 4 (XVI T)

Table 5.5: NPI value for sample 4 from each equation

σ_c=4.2	Eqn. (5.2)	Eqn. (5.3)	Eqn. (5.4)	Eqn. (5.5)	Eqn. (5.6)	Eqn. (5.7)
NPI Through	12.41	20.75	14.72	10.46	2.72	73.40

For sample 5 (XV)

Table 5.6: NPI value for sample 5 from each equation

σ_c=4.67	Eqn. (5.2)	Eqn. (5.3)	Eqn. (5.4)	Eqn. (5.5)	Eqn. (5.6)	Eqn. (5.7)
NPI Through	14.09	23.25	16.62	11.80	3.07	81.77

As value for NPI from Equation (5.7) is much away from original value for coal sample, so this equation can be discarded for this comparison. The reason is, it was formed by pyroclastic flow and fall deposits which are not relevant to coal sample. Further average NPI was taken from five equations as shown in table 5.7

Table 5.7: Average of predicted NPI for sample

Sample ID	Average NPI
LHD-4	8.23
XVI B	12.22
XVII	11.14
XVI T	12.36
XV	13.79

Using this average NPI in equation (5.1) predicted UCS is determined.

Table 5.8: Predicted UCS using average NPI

Sample ID	Average NPI	Predicted UCS using Equation (5.1)
LHD-4	8.23	2.83
XVI B	12.22	3.96
XVII	11.14	3.69
XVI T	12.36	3.99
XV	13.79	4.3

Table 6.1: Measured UCS and predicted UCS

Sample ID	MEASURED UCS (MPa)	PREDICTED UCS (MPa)
LHD-4	2.83	2.83
XVIB	4.15	3.96
XVII	3.8	3.69
XVI T	4.2	3.99
XV	4.67	4.3

When the graph of measured UCS and predicted UCS was plotted, correlation value for logarithmic curve fit was maximum R^2=0.999

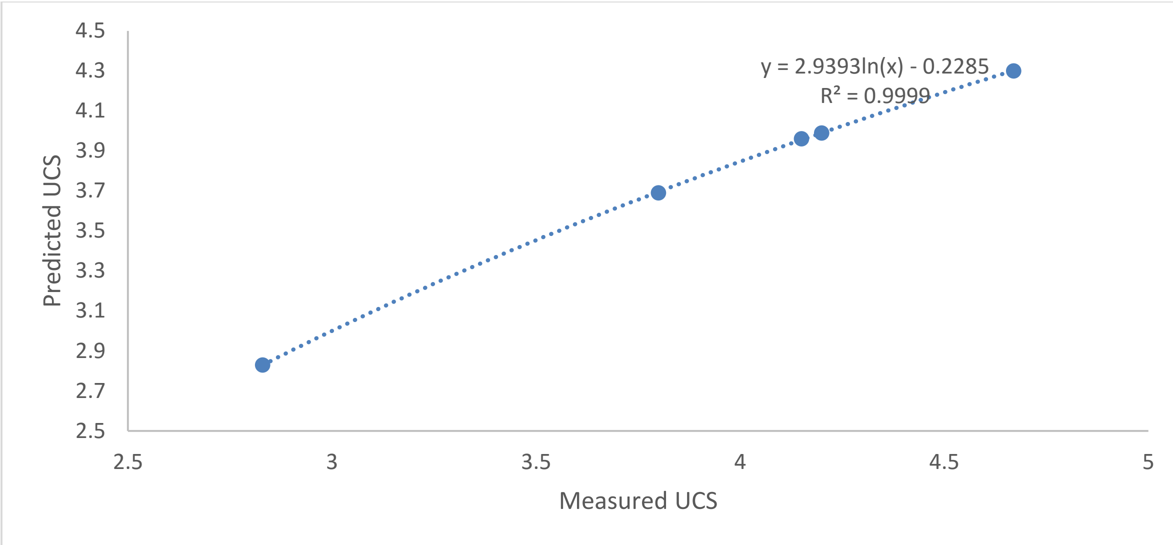


Figure 6.1: Chart showing relation between measured UCS and predicted UCS

This correlation shows that average NPI value through each equation is related to NPI value obtained using device. Based on the relation seen between predicted UCS and measured UCS it was concluded that equation (5.1) can be used for coal sample.

Chapter-6

Conclusion

6.1 CONCLUSIONS

The aim of the investigation was to develop a needle penetrometer and evaluate its performance with respect to a few established approaches on a few samples. The conclusions that were drawn from the same are as below

1. Needle penetrometer is a useful device to measure NPI index which helps in predicting the UCS in an inexpensive mechanism and can be carried out at field relevant result as concluded from equations correlation.
2. The device was developed using mild steel material with a needle of length 30 mm
3. The developed unit was tested for five different coal sample of varying coal seam from 280 m to 580 m.
4. The relationship obtained for coal sample between NPI and UCS is
$$UCS = 2.854 \ln NPI - 3.1856$$
5. Established approaches by Ulusay and Erguler, Aydan, Uchida et al, Okada et al, Takahashi et al and Yamaguchi et al were considered. The graph of measured UCS and predicted UCS was plotted, showed the correleation value R^2=0.999. Based on the relation seen between predicted UCS and measured UCS it was concluded that equation (5.1) can be used for coal sample to predict UCS.

6.2 SUGGESTION FOR FUTURE WORK

The testing was carried out with time constraint, scope is their for testing more number of sample with field testing to study the variation of needle test in different conditions.

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