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Correction for Scale Effect in Computing Point Load Strength Index using Irregular Rock Lumps

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ABSTRACT

Strength of intact rock is an important engineering parameter that is used in the analysis and design of structures founded in rock. Point load strength index test is commonly used for indirect estimation of uniaxial compressive strength of intact rocks. In many situations, these tests are performed on irregular lumps of different sizes. Rock strength is found to be scale dependent and while computing strength index, correction is applied for the size of the lump. Even after the size correction, the point load strength estimated using small size lumps is found to be very high, whereas for large size lumps, it is found to be low. It is believed that area of the lump has a substantial effect on the computed index. The present study suggests a correction for area of the lump. Rock lumps from two different sites of lesser Himalayan region of India were collected. Point load tests were performed and strength index for standard size of 50 mm i.e. Is(50)was calculated. The computed index values were found to be varying in wide range. These index values were analyzed and were found to be correlated with the area of the lump. A correction is suggested to correct the strength index for area and a chart is also proposed for ready to use by field engineers.

Keywords: Irregular lumps; point load strength index; uniaxial compressive strength; Himalaya

1. INTRODUCTION

Himalayan terrains of India are tectonically active with complex geological and geotechnical conditions. The rocks in these regions are dissected by faults, folds and joints. The rock masses are characterized by rugged topography with fragile geology. The major part of lesser Himalayan region is represented by thick sequence of low-grade meta-sediments consisting of Quartzite, Phyllite, Slate and Limestone. Uniaxial compressive strength (UCS) is an important engineering parameter used for design of structures in rocks. To obtain the UCS of intact rock, core specimens with length to diameter ratio (i.e. L/D) of 2.0 to 3.0 are required (ISRM, 1979).Obtaining such core specimens from rocks with poor geological conditions as identified in Himalayan region isvery difficult and at times not feasiblealso. As analternative, indirect testssuch as Point load strength index, Schmidt hammer, Ultrasonic wave velocityand Punch tests are used widely to estimate the UCS approximately.

Point load strength index (PLSI) test is a simple and a well-known method for indirect estimation of UCS when core specimens of required size and shapeare not available. The test can be performed with ease and it enables economical testing of cores or lumps in field or in laboratory especially for the sites of large extent or at preliminary stage of project. There are limitations of

PLSI tests as identified by many researchers (Deere and Miller, 1966; Broch and Franklin, 1972; Bieniawski, 1975; ISRM, 1981; Gunsallus and Kulhawy, 1984; Cargill and Shakoor, 1990; Chau and Wong, 1996; Smith, 1997; Tugrul and Zarif, 1999; Tsiambaos and Sabatakakis, 2004; Palchik and Hatzor, 2004; Fener et al., 2005). Despite having many limitations, the test is used widely to estimate the UCS as it can be performed on specimen having any shape with dimensions varying in wide range. As per ISRM suggested method for point load test (ISRM, 1985), the recommended L/D ratio for axial test is 0.3 to 1. The point load strength index test is simple and quick test. For diametrical test, a minimum L/D ratio of 1.5 is required. In case of block/irregular lumps, the size of specimen equal to50±35 mm is preferable with a thickness (D) to width (W) ratio of about 0.3 to 1 but preferably close to 1.

The rock lumps are generally found in different shapes and sizes depending on the geological condition of the rock mass. As per standards, rock lumps of 50 mm size are considered ideal size for estimating the strength. It is very difficult to get the ideal size of rock lumps especially when the rocks are highly jointed in conjunction with bedding/foliation planes. Thus, the rock lumps in the size range of 15 mm to 85 mm are suggested (ISRM, 1985). The point load strength index is obtained by dividing the failure load by the square of the size of the specimen. The square of size indirectly represents the area of failure surface. The strength of the rock is significantly affected by size and shape of the lumps (Panek and Fannon, 1992). To overcome this, the index obtained from PLSI is corrected to a standard size of 50 mm to obtain strength index, $I_{s(50)}$ (ISRM, 1985). However, despite applying size correction, the computed strength index has been found to be varying in wide range with the area of rock lumps. It indicates that the strength index is still dependent on the area of the lumps. The present study aims at finding out a correction factor for Himalayan rocks depending on the area of the lump to get strength index corresponding to standard size. The suggested correction factor was validated by using test results of point load strength index and UCS of same rock on standard size core specimens. Irregular lumps of two different rock types i.e. Phyllite and Limestone were collected from lesser Himalayan region of India and PLSI tests were performed for wide range of sizes.

2. STUDYAREA

For the present study, two sites from Lesser Himalayan region of India were selected. Site-1 is situated on state highway between Bhagirathipuram and Koteshwar in the district of Tehri Garhwal, Uttarakhand, India. The dominant rocks at this site are Phyllites of Chandpur series in contact with the younger dolomites and quartzites at places (Samadhiya and Jain, 2003). The rock types observed in this region are generally undeformed to deformed Quartzite, Metabasics and Dolomite with bands of Mica, Schist and Phyllite (Tandon and Gupta, 2015). Site-2 is situated on the national highway NH-92 and falls on Mussoorie – Kempty road in the district of Tehri Garhwal, Uttarakhand. The rock types at this site are mainly fractured dolomitic Limestone (Tewari, 2010).At both sites, the rocks are dissected with three sets of persistent joints and one set of random joint. These joint patterns segment the rock mass into blocky structure (Fig. 1).

The outer layer of rock outcrops undergoes repeated cycles of varying meteorological conditions like temperature and rainfall. Due to these repeated cycles, the rock mass degrades in due course of time. Eventually, the outer layer of rock mass becomes poorly disintegrated. Figure 2 shows the highly weathered zones observed at both the sites. It is very difficult to get regular rock lumps of required size from these locations. Therefore, the point load tests were performed on large number of irregular lumps to investigate the effect of area on the computed index.

Figure 1- Inset view of joint pattern observed at site 1 and site 2

Figure 2 - Field photographs showing weathered rock mass observed at sites

3. POINT LOAD STRENGTH INDEX

The point load tests were performed on irregular lumps. The dimensions of the irregular lump are shown schematically in Figure 3. The force required to fail the specimen is the failure load (P) which is used to estimate the uncorrected point load strength index I_s. The strength index ($I_{s(50)}$) corresponding to a size of 50 mm is then calculated using the following equations as suggested by ISRM (1985).

$$I_{s(50)} = F \times I_s = \left(\frac{D_e}{50}\right)^{0.45} \times \frac{P}{D_e^2} \qquad (1)$$

Where, F is size correction factor; $I_s$is point load strength index (PLSI); P is the applied load at peak failure; D_e is the equivalent diameter. D_e = D (i.e. diameter of the core specimen) for diametrical test. $D_e^2 = \frac{4A}{\pi} = \frac{4WD}{\pi}$for axial, block and irregular lump tests, where ‘A’ is minimum cross sectional area of rock lump, which passes through point load irrespective of the area of fracture surface (Fig.3).

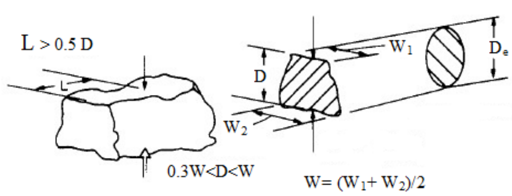

Figure3 - Schematic view of dimensions required for irregular lump specimen

4. ESTIMATION OF UNIAXIAL COMPRESSIVE STRENGTH (UCS)

Numerous studies have established empirical correlations between UCS and $I_{s(50)}$. The UCS can be estimated using following formula:

$$UCS = K \times I_{s(50)} \tag{2}$$

Where, K is a multiplication factor used to estimate the UCS of rock material. Some of the correlations between UCS and $I_{s(50)}$ suggested by different researchers are presented in Table 1. As apparent from Table 1, the suggested value of K may vary in a wide range between about 12 to 25 which indicates that the coefficient K is not constant rather varies with rock type and condition of material. It is therefore appropriate to find out K value for a specific location and litho units.

Table 1 - Correlations between UCS and $I_{s(50)}$

Reference	Correlation
Deere and Miller (1966)	$UCS = 20.7 \times I_{s(50)} + 4.29$
Broch and Franklin (1972)	$UCS=24 \times I_{s(50)}$
Bieniawski (1975)	$UCS=24 \times I_{s(50)}$
ISRM (1985)	$UCS=(20 \text{ to } 25) \times I_{s(50)}$
Ghosh and Srivatsava (1991)	$UCS=16 \times I_{s(50)}$
Ulusay et al. (1994)	$UCS=19 \times I_{s(50)}+12.7$
Chau and Wong (1996)	$UCS=12.5 \times I_{s(50)}$
Smith (1997)	$UCS=14.3 \times I_{s(50)}$
Sulukcu and Ulusay (2001)	$UCS=15.3 \times I_{s(50)}$
Quane and Russel (2003)	$UCS = 24.4 \times I_{s(50)}$
Cobanglu and Celik (2008)	$UCS = 8.66 \times I_{s(50)} +10.85$
Kahraman and Gunaydin (2009)	$UCS = 10.92\ I_{s(50)}+ 24.24$
Heidari et al. (2012)	$UCS = 13.29 \times I_{s(50)} +5.251$
Li and Wong (2013)	$UCS = 20 \times I_{s(50)}$
Aliyu et al. (2019)	UCS = 17.6Is(50) + 13.5

5. LABORATORY STUDY AND ANALYSIS OF RESULTS

Nearly 450-500mm rock lumps were collected from both the sites. As the joints are closely spaced in the rock mass at both the sites, rock lumps in the size range of 15 mm to 85 mm were collected from the slope faces exposed to atmospheric conditions. Width (W) and thickness (D) of the rock specimens were measured and the average width and thickness of the rock specimens were calculated. About 380 tests were performed on Phyllite whereas 60 tests were performed on Limestone lumps. Laboratory test setup for point load test is shown in Figure 4. Load at failure was noted and the point load strength index (i.e. $I_{s(50)}$) was calculated by applying the size correction using equation 1.In order to observe the influence of variation of area (i.e. D×W) on $I_{s(50)}$, the computed $I_{S(50)}$ was plotted versus area as shown in Figure 5. The plots indicate that area of lump has significant effect on Point load strength indexwhich decreases with increasing the lump area. In case of Phyllite, point load strength index was found to be 8 MPa for smaller lumps with an area of 5 cm^2. Whereas, it was found to be low as low as 1.33 MPa in case larger lumps with an area about

30 cm^2. Similarly, in case of Limestone, high point load strength index values 6 to 7 MPa were obtained when the area of lump was small (5 cm^2) while for large size lumps (with area of 50 to 60 cm^2), the strength index reduced to around 2 MPa. The large variation in computed $I_{s(50)}$ values indicate that further area correction is required. It was therefore attempted to get a correction between computed $I_{s(50)}$ and area of the specimen. The following steps were followed for this purpose:

- Computed $I_{s(50)}$ values were arranged in ascending order of the lump area.
- The $I_{s(50)}$ values were grouped into classes depending on class interval of area. The frequency distribution of $I_{s(50)}$ values of each class interval is summarized in Table 2.
- Mean value of $I_{s(50)}$ of each class was calculated and it was considered as the representative value for that class.
- Similarly, mean value of area was calculated for each class interval.
- The plot between the mean value of $I_{s(50)}$ and mean value of lumparea was drawn for both the rock types (Fig. 6).
- It was found that $I_{s(50)}$ decreases rapidly upto area of 25 cm^2. For area higher than 25 cm^2 the reduction was relatively low. The best-fitting curve was selected (Fig. 6) and the correlationsfor each rock type are expressed as follows:

  $I_{s(50)} = -2.07 \ln(A)+8.95$ for Phyllite (3)

  $I_{s(50)}= -1.27 \ln(A)+7.29$ for Krol Limestone (4)

  where A = Area of lump in cm^2 and $I_{S(50)}$ in in MPa.

- Since the standard size of block/irregular lump recommended for point load strength index tests is 50 mm × 50 mm (i.e. equivalent to the area of 25 cm^2) as per the ISRM (1985), $I_{s(50)}$ corresponding to this is considered to be representing for standard size. The same was denoted as $I_{s(50)\_std}$.
- The Index values were re-calculated using equation 3 and equation 4, and denoted as $I_{s(50)\_re}$. The ratio $I_{s(50)\_std}/I_{s(50)\_re}$ was used as correction factor to obtain the strength equivalent to lump area of 25 cm^2. A chart (Fig.7) has been suggested to get correction factor (Fig. 7). The same may be used to correct the obtained $I_{s(50)}$ for two given rock types.

Table 2 - Summary of tests data distribution grouped under area

S.No	Site-1 Phyllite rock samples				Site-2 Krol Limestone rock samples			
	Class interval of area, cm^2	No. of tests data	Mean area, cm^2	Mean $I_{s(50)}$, MPa	Class interval of area, cm^2	No. of tests data	Mean area, cm^2	Mean $I_{s(50)}$, MPa
1	4-5	4	4.84	5.94	2-3	1	2.79	5.86
2	5-6	8	5.54	5.30	4-5	1	4.14	4.84
3	6-7	29	6.63	5.03	5-6	3	5.55	5.01
4	7-8	29	7.46	4.31	6-7	3	6.66	4.42
5	8-9	42	8.52	4.85	7-8	5	7.14	4.42
6	9-10	37	9.57	4.29	8-9	6	8.42	4.16
7	10-11	36	10.41	3.98	9-10	4	9.54	4.22
8	11-12	48	11.55	4.04	10-11	5	10.56	4.76
9	12-13	21	12.51	3.15	11-12	5	11.66	5.58
10	13-14	21	13.43	3.02	15-16	3	16.31	3.57

11	14-15	17	14.35	3.49	18-19	2	18.71	2.82
12	15-16	13	15.45	3.82	20-21	2	20.27	4.52
13	16-17	7	16.55	3.03	23-24	2	23.18	5.29
14	17-18	11	17.44	3.43	25-26	1	25.50	3.63
15	18-19	13	18.46	2.52	27-28	2	27.23	4.31
16	19-20	9	19.29	3.09	30-31	1	31.78	2.54
17	20-21	5	20.59	2.83	34-35	1	34.32	2.45
18	21-22	6	21.55	3.75	38-39	1	38.43	1.27
19	22-23	3	22.57	2.48	50-51	1	50.59	2.21
20	23-24	4	23.36	3.38	51-52	1	51.57	2.73
21	24-25	4	24.43	2.01	57-58	1	57.74	2.05
22	26-27	4	26.39	2.42	62-63	1	62.12	1.32
23	27-28	1	27.01	1.91	76-77	2	76.53	1.08
24	28-29	2	28.44	1.98	87-88	1	87.01	1.74
25	29-30	2	29.43	1.86	--	--	--	--
26	30-31	2	30.40	1.74	--	--	--	--
27	32-33	1	32.43	1.36	--	--	--	--
28	34-35	1	35.29	1.42	--	--	--	--

Figure 4 - Laboratory test setup for point load test

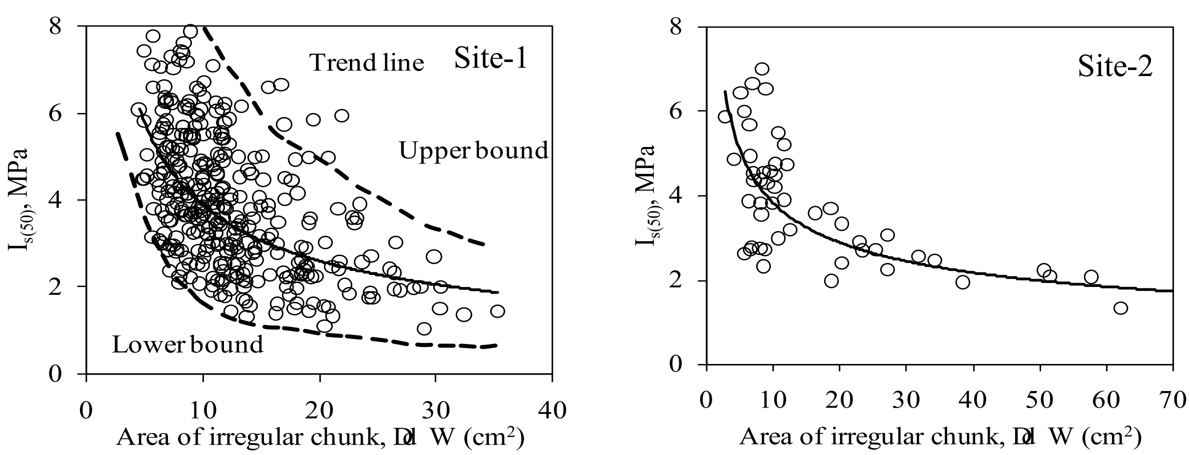

Figure5 - Variation of $I_{s(50)}$ with plan area of lumps

It is observed that size correction factor is almost identical for these two rocks with area less than 25 cm^2. However, for area higher than 25 cm^2, there is a larger deviation. It is therefore, preferable to test smaller size specimens as compared to large size specimens. Further, this type of studies needs to be performed on other rock types as well. Hence, small lumps of rock joint asperities may be tested by point load tests to predict its joint wall compressive strength (JCS) approximately in cases of even the weathered rock masses.The point load tests on small lumps may also be used for the quality control of concrete aggregates.

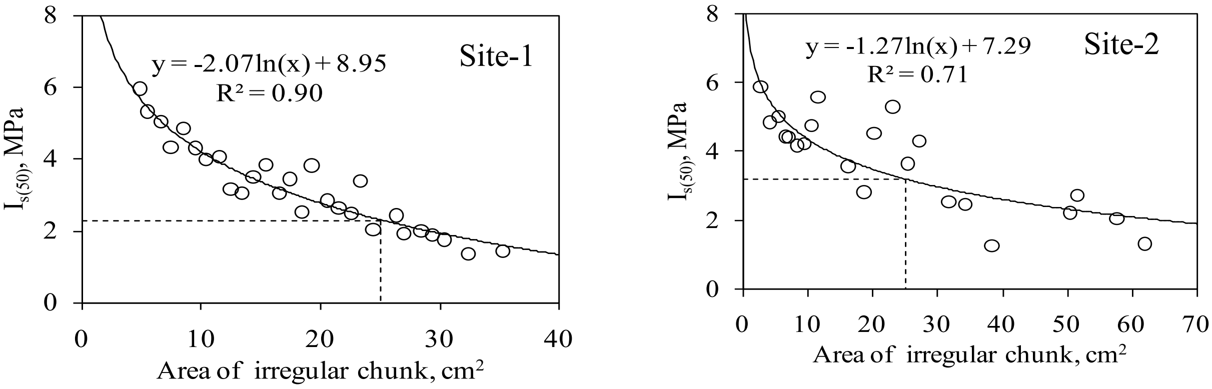

Figure 6 - Variation of $I_{s(50)}$ with plan area of lump

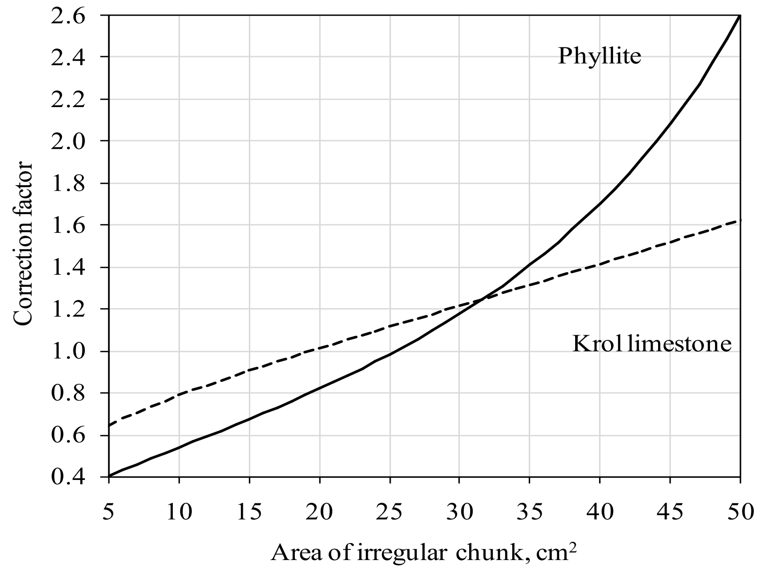

Figure 7 - Proposed chart for the correction factor of plan area

6. VALIDATION OF SUGGESTED AREA CORRECTION

To validate the chart proposed from the present study, another set of Phyllite rock lumps collected from the slope face were used to perform the PLSI tests. As per ISRM recommendations, testing of at least 10 specimens out of one sample needs to be performed. Following this, around 20 specimens of rock lumps were selected to perform PLSI tests. PLSI was estimated and size correction was applied to get $I_{s(50)}$. The mean, variance and standard deviation of $I_{s(50)\_std}$ are 5.72, 2.37 and 1.54 respectively. UCS for the mean value of $I_{s(50)}$ was computed using a value of K≈15-20 and it was found to be varying between 85.79 to 114.39 MPa. The summary of the results is presented in Table 3. Rock blocks, which were relatively in better quality, were collected from deeper depth. Core specimens of NX size with L/D ratio equal to 2 were prepared and two UCS tests were performed. Figure 8 shows failed specimen and stress-strain plots for core specimens. The mean value of strength from UCS tests was found to be 61.42 MPa. The range of strength from uncorrected Point Load strength index (85.79 to 114.39 MPa) is relatively very high compared to that obtained from UCS tests. On the contrary, the lumps tested were relatively weathered as compared to core specimens, and it was expected that strength from rock lumps should be relatively lower than that from fresh cores. Now, the area correction as proposed in the present study was applied to all $I_{s(50)}$ values. The mean, variance and standard deviation of corrected strength index i.e. $I_{s(50)\_re}$ are obtained and they are found to be 3.01, 0.75 and 0.86 respectively (Table 3). Using K ranging from 15 to 20 the computed strength is found to vary in the range of 45.15 to 60.2 MPa. It is seen that the computed strength based on corrected $I_{s(50)}$ are very close to the UCS test results and are relatively on lower side of strength obtained from UCS tests on fresh cores. The variance and standard deviation of $I_{s(50)}$ are found to be very low which indicate obtained $I_{s(50)}$ of each specimen after the proposed area correction is close to mean value. It is therefore concluded that the proposed correction may be used with confidence. It can also be concluded that the coefficient K for Phyllite for the present region may be taken equal to slightly lower than 20.

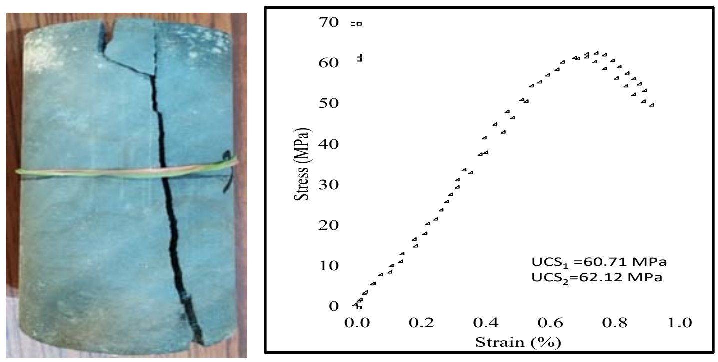

Figure 8 - Failed specimen and stress-strain plot of Phyllite specimen

Table 3 - Summary of point load tests data

S.No	D (mm)	W (mm)	Computed $I_{s(50)}$(MPa)	D ×W (cm^2)	Correction factor	Corrected $I_{s(50)}$(MPa)
1	16.73	40.77	8.62	6.82	0.46	3.93
2	21.73	50.17	3.91	10.90	0.57	2.21
3	24.07	45.4	4.79	10.93	0.57	2.71
4	21.87	48.43	3.36	10.59	0.56	1.87
5	18.97	61.00	7.23	11.57	0.58	4.22
6	19.00	60.60	4.99	11.51	0.58	2.91
7	25.00	62.67	6.58	15.67	0.70	4.58
8	17.73	63.40	6.04	11.24	0.58	3.47
9	17.50	42.63	5.17	7.46	0.47	2.45
10	14.23	35.33	8.28	5.03	0.40	3.35
11	16.47	40.83	3.21	6.72	0.45	1.45
12	15.60	36.50	7.10	5.69	0.42	3.01
13	15.40	29.63	6.07	4.56	0.39	2.37
14	48.13	18.37	6.09	8.84	0.51	3.11
15	51.10	25.63	7.72	13.10	0.63	4.83
16	44.80	22.33	4.52	10.01	0.54	2.45
17	44.00	26.73	4.28	11.76	0.59	2.52
18	41.13	20.27	5.67	8.34	0.50	2.82
19	61.23	18.40	5.04	11.27	0.58	2.90
Mean value of $I_{s(50)\ std}$			5.72	Mean value of $I_{s(50)\ re}$		3.01
Variance			2.37	Variance		0.75
Standard deviation			1.54	Standard deviation		0.86
UCS (=15 to 20 $I_{s(50)}$)			85.79-114.39	UCS (=15 to 20 $I_{s(50)}$)		45.15-60.2

7. CONCLUDING REMARKS

The strength of intact rock is an important parameter required for analysis and design of structures in rocks. In many field situations in Himalayan region, it is very difficult to procure regular cylindricalspecimens of required length to diameter ratio. Hence, point load strength index tests are performed on irregular lumps. Point load strength index $I_{s(50)}$is obtained by applying size correction and then coefficient K is used to estimate the uniaxial compressive strength (UCS). The obtained strength index has been found to be varying with the area of the lump. In the present study irregular lumps of different sizes were collected from two sites of lesser Himalayan region. Point load tests were carried out and tests data were analyzed to investigate the variation of strength index with the area of lump. The results indicate that despite applying usual size correction the $I_{s(50)}$varies in wide range with area. A correction has been suggested in the present study to obtain corrected index. The correction factor has been suggested for two rock types i.e. Phyllite and Limestone which are found in abundance in Indian Himalaya. The results for Phyllite rock were also validated through independent tests. It is suggested that similar corrections may be developed for other rock types as well.

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