

# Influence of Anisotropy on Correlation Between Point and Line Loads, Inducing Indirect Tension

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## Abstract

To measure the tensile strength, the load applied can be either tensile or compressive. The application of compressive load in order to induce tensile stresses can be either through point load (diametral loading) or line load. In this paper, for twelve variants of basalt and twelve variants of gneiss, an attempt has been made to correlate the two loads, i.e., point load and line load, to induce tensile failure. For each of the variants, the correlation between the point load and the line load data is discussed on the basis of recommended parameters only; in other words, the inherent variability of a given variant is not in focus here. The reported work also draws from previous researches and codes of practice. In case of Basalts, the ratios are ranging from 0.65 to 0.78. While, due to anisotropy in Gneisses, the ratio is ranging from 0.79 to 2.28, but, it is also observed that the ratio is decreasing to 0.80 as the value of anisotropy index is approaching unity. However, it can easily be inferred from the study that the ratio is rock type specific.

**Keywords: Anisotropy, Point and Line Loads**

## I. INTRODUCTION

In case of a rockmass, it is necessary to understand the combination of initial stresses and stresses induced by the construction and operation of a structure, as these may cause rock failure. It is important to understand the strengths (compressive, tensile, flexural, and shear) and other parameters of the rockmass and the redistribution of stresses due to the rock-structure interaction.

Since, rock is a naturally occurring material and, in terms of physical properties and strength parameters, it has high inherent variability. It is observed that, at times, the properties and parameters of rock change horizontally and vertically at short distances, even if the geological nomenclature is same. However, in the preliminary stage of any mega project (while selection of alternatives for foundation), it is not feasible to investigate the rock for each property or parameter. So, it is desirable to have a correlation of strength parameters with a parameter which can be conducted at site with a portable setup (Portable Point Load Test Apparatus considered in the present case) and requires no sample preparation.

In rock mechanics, Line Load Test (Brazilian Test) is a common test for the determination of indirect tensile strength, while Point Load Strength Index Test (more accurately, the double point load test) is common in structural geology (McWilliams, 1966). The apparatus for conducting point load strength test being portable, the test being quick, and practically no sample preparation needed, point load strength test could be conducted for feasibility study and its correlation with other parameters established. For the assessment of point load strength, the rock specimens in the form of core/ block/ lump are loaded up to failure by the application of concentrated load through a sphere of truncated conical platens.

In this paper, an attempt has been made to correlate the representative values of point load strength with that to Brazilian test results, for 12 Massive Basalts from different locations in India and 12 variants of Gneisses from different locations in India and Bhutan (tested in CSMRS Laboratory). Here, representative values of all the said variants of both tests are considered for analysis, so that the inherent variability within the rock cores can be compensated, in turn the representative value is representative of more than 10 samples tested (minimum number specified in the standards) for each variant. The Brazilian test requires sample preparation and cannot be performed at site (without cutting and polishing setup). The reasons for correlating point load strength with Brazilian test results are as under:

- 1) The loading in both the tests is compressive, which induces indirect tension in the sample and causes a tensile failure.
- 2) Brazilian test results are accepted worldwide and the same are considered comparable with direct tensile strength.
- 3) Literatures have many correlations of Brazilian test results with other properties and parameters for different rock variants.

It is also important to note that, in literature, the phenomenon of high compressive stress concentration causing tensile fracture in the underground opening is referred as axial cleavage fracture (Gramberg, 1965), slabbing (Coates, 1970), and rock splitting (Fairhurst and Cook, 1966). Many researchers have suggested that the initiation of fractures in brittle materials is a tensile phenomenon (Haimson and Cornet 2003; Myer et al. 1992; Stacey 1981; Taponnier and Brace 1976; Griffith 1921). If tensile fracture can be a mechanism of failure in rocks, more attention needs to be paid to the tensile strength of rocks.

In this paper, after a brief discussion on the work done by earlier researches in this area, the correlation between the Point load and the Line Load is explored, along with the influence of anisotropy on the test results. The representative values (to eliminate the influence of the inherent variability of rock) of the twelve variants of Massive Basalt and Twelve variants of Gneiss tested under the point load and the line load form the basis of the presented study.

## II. EARLIER RESEARCHES

Mostly, rockmass is under the influence of compressive forces; but under some conditions, such as underground openings, the role of the tensile strength of the rock becomes crucial. Moreover, invariably, the crack is initiated in most of the rocks because of the tensile stress. So, it is necessary to study the tensile stresses of the rock. Conventionally, there is procedure to evaluate direct tensile strength of any material and same can be applied to the rocks too. However, there are issues associated with testing, particularly that of holding the specimen for application of direct tensile stress. Moreover, the procedure is cumbersome as well. Also, in real life, seldom, direct tensile stresses act on the rockmass. Because of the foregoing reasons, the determination of tensile strength through indirect methods has become popular.

Fairhurst (1964) pointed out that, for very small angles of contact area, failure may occur away from the centre of the test disc. Later, Colbak (1966) supported the argument of origin of failure from the centre of the specimen, while Hudson (1972) was of the view that the failure would initiate from the centre only when flat steel platens are used for loading the specimens.

As pointed out by ISRM Suggested Methods, experimentally it has been proved that most of the rocks in biaxial stress fields fail in tension at their uniaxial tensile strength, when the magnitude of the compressive principal stress does not exceed three times that of the principal tensile stress (ISRM 1978).

The validity of indirect methods of assessment of tensile strength is based on certain conditions. For example, the test will be considered as invalid if the failure plane and the line of loading do not coincide, and/ or the failure plane does not originate from the centre of the specimen.

Many researchers have proposed correlations between the failure loads of the point load strength index (under diametral loading) ( $P_P$ ) and the line load of the Brazilian Test (indirect tensile strength), ( $P_L$ ). The underlying assumption, on which these comparisons are based, is that irrespective of the loading pattern, i.e., method of inducing tensile stress, the tensile stress at failure is equal. Table 1 lists the references and the ratio ( $P_P / P_L$ ), along with the mode of assessment.

It can be observed from Table 1 that Forcht (1948) and IS code suggested that the Point Load required for failure is more than the corresponding line load. All other quoted sources proposed that  $P_P$  is less than the corresponding  $P_L$ ; and for the cited works, the ratio ( $P_P/P_L$ ) ranges from 0.26 to 0.45. Amongst the discussed studies, only Lajtai (1980) made it explicit that his work was based on sandstone, and no other researcher discussed the influence of the rock-type on the proposed correlation. However, it is obvious that the proposed ratios by different researchers would have best fitted the data on which the respective researchers worked. So, it can be said that the correlations are site specific and not universal.

Table – 1  
Previously set correlations between point load and line load

| <i>S. No.</i> | <i>Researcher/ Reference</i> | <i><math>P_P / P_L</math></i> | <i>Method of study</i>                    |
|---------------|------------------------------|-------------------------------|---|
| 1             | <i>Forcht (1948)</i>         | 2                             | <i>Theoretical Interpretation</i>         |
| 2             | <i>McWilliams (1966)</i>     | 0.45                          | <i>Empirical correlation</i>              |
| 3             | <i>Peng (1976)</i>           | 0.33                          | <i>Finite Element Numerical Technique</i> |
| 4             | <i>Lajtai (1980)</i>         | 0.26                          | <i>Experimental Basis (Sandstone)</i>     |
| 5             | <i>IS:10082:1981</i>         | 1.33                          | <i>Not specified</i>                      |

## III. PRESENT WORK

In this study, the Line Load Test (Brazilian Test) and the Point Load Strength Index Test (diametral) have been performed on the samples of 12 variants of basalt and 12 variants of gneiss, as per relevant ISRM and BIS codes. The procedures adopted are as under:

### A. Brazilian Test

Right circular cylinders with length to diameter ratio of 0.5 are prepared, and the compressive line load is applied through Universal Testing Machine. These samples are loaded diametrically, with the axes of rotation of the specimen and apparatus coincident. The samples are failed such that the failure originates from the centre and passes through the line of loading. If any of the two said conditions are not met the samples are to be rejected.

### B. Point Load Test

For the assessment of Point Load Strength, the rock specimens in the form of core are diametrically loaded up to failure by application of concentrated load through a sphere of truncated, conical platens. And, the test is rejected as invalid if the fracture plane does not contain the line passing through points of loading.

IV. DISCUSSION

Table 2 shows the failure loads and anisotropy index of Basalts and Gneisses. The strength anisotropy index ( $I_a$ ) has also been evaluated through Point Load Strength Index (IS:8764:1998) and discussed ahead, in order to highlight an additional dimension needing attention in further analysis. The test measures the Point Load Strength Index of rock specimens, and their Strength Anisotropy Index ( $I_a$ ), which is the ratio of point load strength indices in directions that give the greatest (axial loading) and least values (diametral loading).

Table – 2  
Failure loads and anisotropy index of Basalts and Gneisses

| S No. | Rock type      | $P_L$ | $P_P$ | $P_P/P_L$ | $I_a$ | S. No. | Rock type          | $P_L$ | $P_P$ | $P_P/P_L$ | $I_a$ |
|-------|----------------|-------|-------|-----------|-------|--------|--------------------|-------|-------|-----------|-------|
|       |                | KN    | KN    |           |       |        |                    | KN    | KN    |           |       |
| 1     | Massive Basalt | 25.2  | 14.1  | 0.56      | 1.10  | 1      | Variants of Gneiss | 7.2   | 16.4  | 2.28      | 1.7   |
| 2     |                | 29.8  | 21.1  | 0.71      | 1.07  | 2      |                    | 5.1   | 11.1  | 2.17      | 1.6   |
| 3     |                | 25.2  | 16.9  | 0.67      | 1.05  | 3      |                    | 5.3   | 10.0  | 1.90      | 1.5   |
| 4     |                | 19.0  | 14.4  | 0.76      | 1.03  | 4      |                    | 6.9   | 12.2  | 1.75      | 1.5   |
| 5     |                | 20.0  | 15.6  | 0.78      | 1.03  | 5      |                    | 8.8   | 13.3  | 1.51      | 1.4   |
| 6     |                | 25.2  | 18.3  | 0.73      | 1.00  | 6      |                    | 10.0  | 14.2  | 1.42      | 1.3   |
| 7     |                | 34.3  | 22.5  | 0.66      | 1.00  | 7      |                    | 9.0   | 13.8  | 1.53      | 1.3   |
| 8     |                | 38.9  | 25.4  | 0.65      | 1.00  | 8      |                    | 12.0  | 16.4  | 1.37      | 1.3   |
| 9     |                | 27.5  | 19.7  | 0.72      | 1.00  | 9      |                    | 18.0  | 18.4  | 1.02      | 1.2   |
| 10    |                | 11.4  | 8.5   | 0.74      | 1.00  | 10     |                    | 21.0  | 18.4  | 0.88      | 1.1   |
| 11    |                | 13.7  | 9.9   | 0.72      | 1.00  | 11     |                    | 28.3  | 23.5  | 0.83      | 1.0   |
| 12    |                | 25.2  | 16.9  | 0.67      | 1.00  | 12     |                    | 31.0  | 24.5  | 0.79      | 1.0   |

A. Massive Basalt

For each of the twelve rock variants, for point loading as well as for line loading, at least ten samples each have been tested. The representative failure loads (point versus line) are plotted in Figure 1. The plot suggests that, for the investigated basalt, the required point load is less than the line load. And, there is a linear relationship between the two failure loads, with sufficiently good coefficient of correlation ( $r^2$ ) value of 0.9352. The experimental data (Table 2) shows that, by enlarge, the investigated basalt is quasi isotropic (i.e., anisotropy index is 1). And, the ratio ranges from 0.65 to 0.78.

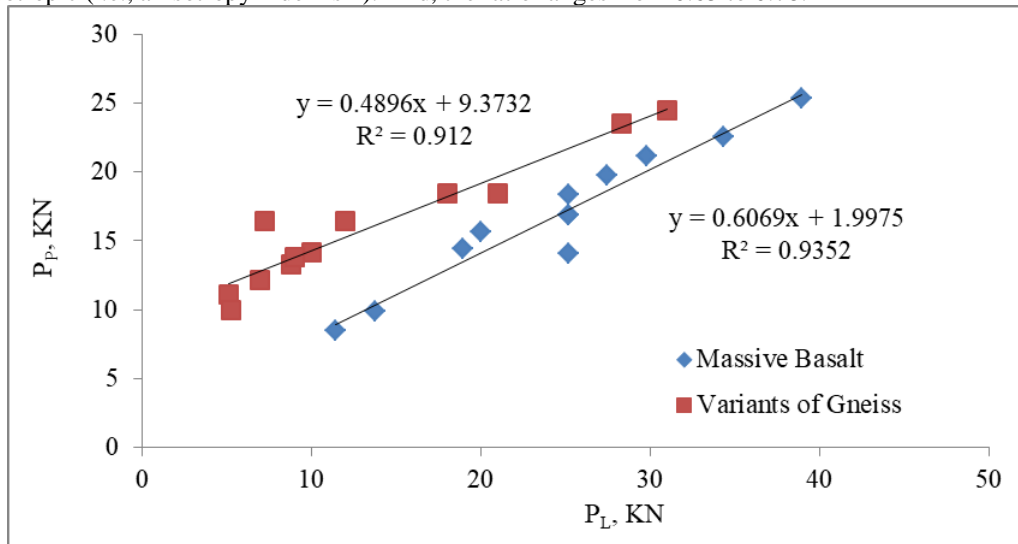


Fig. 1:  $P_P$  versus  $P_L$

Here, the data set have been considered conclusive as the Brazilian strength of the considered Massive Basalt is ranging from 5 to 17MPa. In view of the above, for Massive basalt, the ratio of point and line loads comes out to be 0.71 (average of all except 0.56), unlike stated in the standard and works done by other researchers (Table 1). For the considered data set, using the stated ratio and the point load assessed, the Brazilian indirect tensile strength is calculated and the error is within 10% (ignoring one variant), which is less than the inherent variability of a rock variant (Shown in Table 3).

Table – 3  
% Error in assessing Brazilian indirect tensile strength (Massive Basalt)

| Basalt     |            |                 |           |          |
|------------|------------|-----------------|-----------|----------|
| $P_{Lcal}$ | $\sigma_t$ | $\sigma_{tCal}$ | Error (%) | Sorted % |
| 19.84      | 11.00      | 8.67            | 21.22     | 0.01     |
| 29.75      | 13.00      | 13.00           | 0.01      | 1.10     |

|       |       |       |      |       |
|-------|-------|-------|------|-------|
| 23.80 | 11.00 | 10.40 | 5.47 | 1.10  |
| 20.26 | 8.28  | 8.85  | 6.84 | 2.41  |
| 21.97 | 8.73  | 9.60  | 9.91 | 3.99  |
| 25.79 | 11.00 | 11.27 | 2.41 | 5.47  |
| 31.74 | 15.00 | 13.87 | 7.57 | 5.47  |
| 35.71 | 17.00 | 15.60 | 8.25 | 6.84  |
| 27.77 | 12.00 | 12.13 | 1.10 | 7.57  |
| 11.90 | 5.00  | 5.20  | 3.99 | 8.25  |
| 13.89 | 6.00  | 6.07  | 1.10 | 9.91  |
| 23.80 | 11.00 | 10.40 | 5.47 | 21.22 |

**B. Gneiss**

For each of the twelve rock variants, for point loading as well as for line loading, at least ten samples each have been tested. The representative failure loads (point versus line) are plotted in Figure 1. The plot suggests that for the investigated gneisses, for lower values of failure load, the required point load is less than the line load. And, there is a linear relationship between the two failure loads, with coefficient of correlation ( $r^2$ ) value of 0.912.

Figure 2 shows the anisotropy index of the eight rock variants. It can be observed from Figure 2 and Table 2 that, with the decrease in anisotropy index, the ratio of the point load and line load is decreasing and the ratio is reducing to 0.8 as the anisotropy index is approaching unity (very close to that of Massive Basalt). It can be inferred that the anisotropy index is affecting the ratio.

Here, the data set have been considered conclusive as the Brazilian strength of the considered variants of Gneiss is ranging from 2 to 14MPa. In view of the above, for Gneissic variants, the ratio of point and line loads is depended on anisotropy index, unlike stated in the standard and works done by other researchers (Table 1). And, the relation between the two is as under.

$$P_p/P_L = 2.072 I_{(a)} - 1.2975$$

For the considered data set, using the point load and anisotropy index assessed from Portable Point Load Apparatus, and the stated relation, the Brazilian indirect tensile strength is calculated and the error is within 10% (ignoring one variant), which is less than the inherent variability of a rock variant (Shown in Table 4).

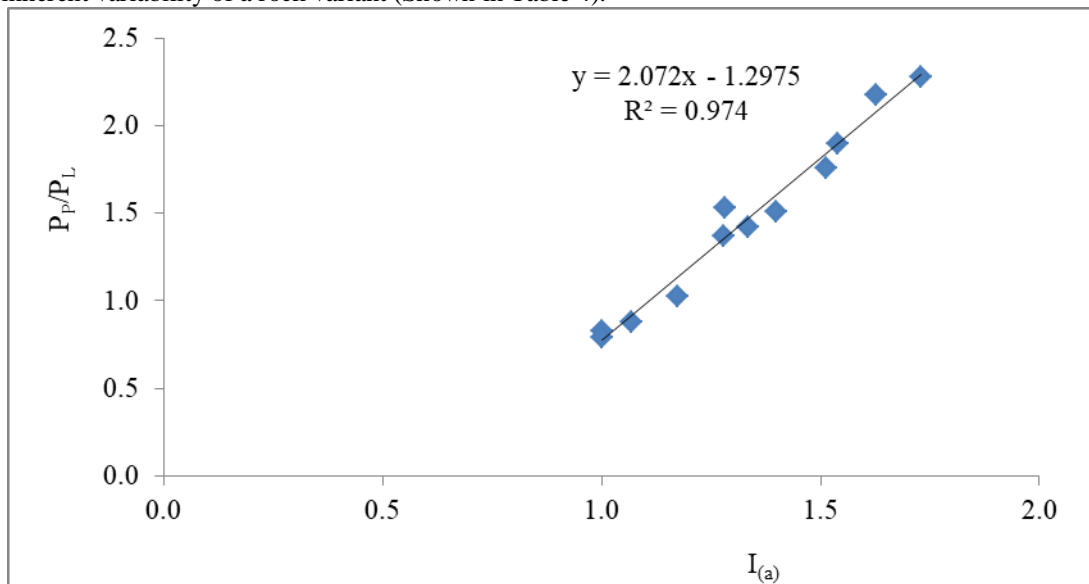


Fig. 2: Anisotropy Index ( $I_a$ ) of Gneiss

Table – 4  
% Error in assessing Brazilian indirect tensile strength (Gneiss)

| <i>Gneiss</i> |            |                 |           |          |
|---------------|------------|-----------------|-----------|----------|
| $P_{Lcal}$    | $\sigma_t$ | $\sigma_{tcal}$ | Error (%) | Sorted % |
| 7.17          | 3.15       | 3.13            | 0.48      | 0.25     |
| 5.34          | 2.22       | 2.33            | 4.92      | 0.48     |
| 5.26          | 2.29       | 2.30            | 0.25      | 1.03     |
| 6.63          | 3.03       | 2.90            | 4.38      | 2.04     |
| 8.30          | 3.83       | 3.63            | 5.41      | 3.08     |
| 9.69          | 4.37       | 4.23            | 3.08      | 3.99     |
| 10.17         | 3.93       | 4.44            | 12.97     | 4.38     |
| 12.12         | 5.24       | 5.30            | 1.03      | 4.92     |
| 16.27         | 7.86       | 7.11            | 9.59      | 5.41     |

|              |              |              |             |              |
|--------------|--------------|--------------|-------------|--------------|
| <b>20.16</b> | <b>9.17</b>  | <b>8.81</b>  | <b>3.99</b> | <b>7.22</b>  |
| <b>30.34</b> | <b>12.36</b> | <b>13.26</b> | <b>7.22</b> | <b>9.59</b>  |
| <b>31.63</b> | <b>13.54</b> | <b>13.82</b> | <b>2.04</b> | <b>12.97</b> |

## V. CONCLUSION

The present study deals with two rock types, namely basalt and gneiss. It involves twelve variants of basalt and twelve variants of gneiss, purely on the basis of the representative values of the failure loads in point loading and line loading cases. In case of basalts, the ratios are ranging from 0.65 to 0.78. While, due to anisotropy in gneisses, the ratio is ranging from 0.79 to 2.28, but, it is also observed that the ratio is decreasing to 0.80 as the value of anisotropy index is approaching unity. However, it can easily be inferred from the study that the ratio of the two is rock type specific.

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